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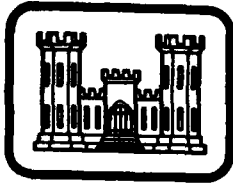
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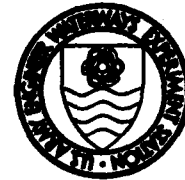




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TECHNICAL REPORT C-78-4

# MAINTENANCE AND PRESERVATION OF CONCRETE STRUCTURES

Report 3

## ABRASION-EROSION RESISTANCE OF CONCRETE

by

Tony C. Liu

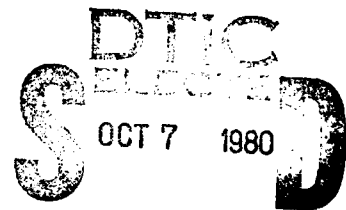
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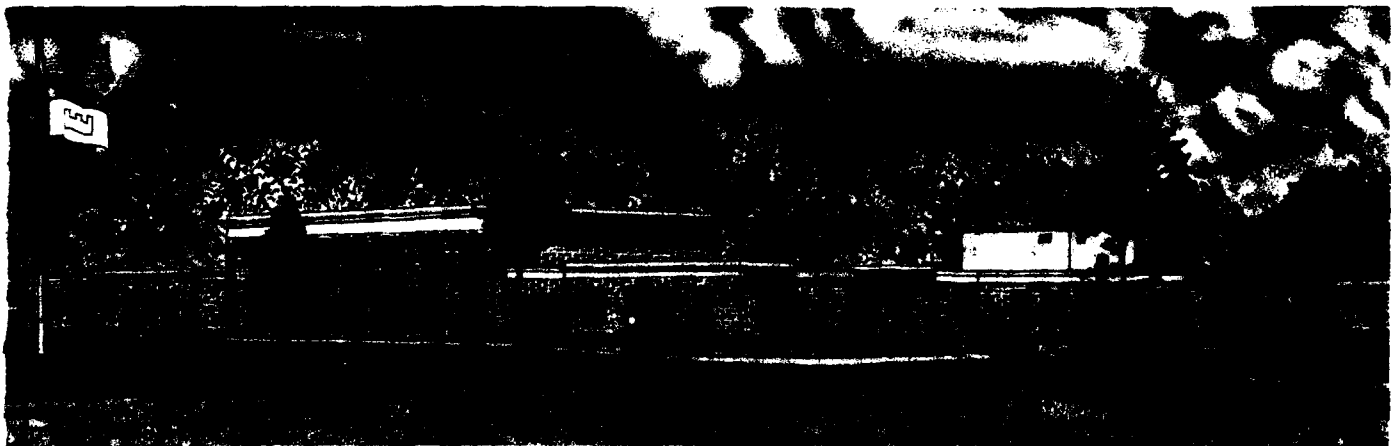
July 1980

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Under CWI Work Unit 31553

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<b>Report 3: Abrasion-Erosion Resistance of Concrete</b>	<b>July 1980</b>

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A laboratory test program on abrasion-erosion resistance of concrete, including the development of a new underwater abrasion-erosion test method, described. The test program was designed to evaluate the relative abrasion-erosion resistance of various materials considered for use in the repair of erosion-damaged concrete structures.  The test program encompassed three concrete types (conventional concrete,  (Continued)		

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20. ABSTRACT (Continued).

fiber-reinforced concrete, and polymer concrete); seven aggregate types (limestone, chert, trap rock, quartzite, granite, siliceous gravel, and slag); three principal water-cement ratios (0.72, 0.54, and 0.40); and six types of surface treatment (vacuum, polyurethane coating, acrylic mortar coating, epoxy mortar coating, furan resin mortar coating, and iron aggregate topping). A total of 114 specimens made from 41 batches of concrete was tested.

Based on the test data obtained, a comprehensive evaluation of the effects of various parameters on the abrasion-erosion resistance of concrete was presented. Materials suitable for use in the repair of erosion-damaged concrete structures were recommended. Additional work to correlate the findings ~~reported herein~~ with field performance was formulated.

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## PREFACE

The study reported herein was conducted in the Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES), under the sponsorship of the Office, Chief of Engineers (OCE), U. S. Army, as a part of Civil Works Investigation Work Unit 31553. The study was authorized 16 February 1977 by first indorsement to a WES letter dated 3 January 1977. Messrs. James A. Rhodes and Fred Anderson of the Structures Branch, Engineering Division, OCE, served as technical monitors.

The study was conducted under the general supervision of Mr. Bryant Mather, Chief, SL, and Mr. John Scanlon, Chief, Concrete Technology Division, and under the direct supervision of Mr. James E. McDonald, Chief, Evaluation and Monitoring Group, SL. The tests were conducted by Dr. Tony C. Liu and Messrs. J. T. Peatross and F. W. Dorsey. Mr. W. B. Lee developed mixture proportions and fabricated all test specimens. Concrete specimens containing polymer and surface coatings were prepared by Mr. T. Husbands. This report was prepared by Dr. Tony C. Liu.

The Commanders and Directors of the WES during this study and the preparation and publication of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. Fred R. Brown.

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CONVERSION FACTORS, INCH-POUND TO METRIC (SI)  
UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic feet	2.831685	cubic metres
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet per second	0.3048	metres per second
gallons (U. S. liquid)	3.785412	cubic metres
inches	25.40000	millimetres
inch per inch per Fahrenheit degree	5/9	centimetre per centimetre per Celsius degrees or Kelvins*
ounces (U. S. fluid)	0.0000284	cubic metres
pounds (force)	4.448222	newtons
pounds (force) per linear inch	175.1268	newtons per metre
pounds (force) per square inch	6894.757	pascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic yard	0.5932764	kilograms per cubic metre

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\* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula:  $C = (5/9)(F - 32)$ . To obtain Kelvin (K) readings, use:  $K = (5/9)(F - 32) + 273.15$ .

MAINTENANCE AND PRESERVATION OF  
CONCRETE STRUCTURES

ABRASION-EROSION RESISTANCE OF CONCRETE

PART I: INTRODUCTION

1. Investigation of maintenance and preservation problems associated with civil works concrete structures was initiated in February 1977 at the U. S. Army Engineer Waterways Experiment Station (WES). The overall objective of this investigation is to develop information necessary to insure the continued safety of dams and other civil works structures: specifically, (a) to develop and evaluate materials and techniques for repair and rehabilitation of civil works structures, (b) to develop engineering guidance for evaluating and monitoring the safety of structures, and (c) to develop design and construction methods for rehabilitating older structures to comply with current structural design criteria.

2. The first step in this investigation was to review techniques and materials that have been used in the repair and rehabilitation of stilling basins. A survey of the various Corps of Engineers Divisions and Districts identified 52 structures that have experienced concrete damage due to abrasion-erosion (McDonald 1980). Depths of erosion ranged from a few inches\* to approximately 10 ft (Figure 1). In general, this erosion damage resulted from the abrasive effects of waterborne rocks and other debris being circulated over the concrete surface during construction and operation of the structure.

3. The majority of the structures surveyed have been repaired, using a variety of materials and techniques with varying degrees of success. Repair materials include conventional concrete, epoxy resins, fiber-reinforced concrete, and polymer-impregnated concrete. In many

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\* A table of factors for converting inch-pound units of measurement to metric (SI) units is presented on page 3.



Figure 1. Erosion of stilling basin floor slab, Dworshak Dam

instances materials have been used in prototype repairs with limited or no laboratory evaluation of their effectiveness in the particular application. This survey showed a definite need for such material evaluations, particularly erosion resistance, prior to using these materials in prototype repairs costing millions of dollars. Consequently, the study reported herein was conducted to evaluate the relative abrasion-erosion resistance of various materials considered for use in repair of erosion-damaged concrete structures.

## PART II: TEST METHOD DEVELOPMENT

4. Various test methods have been used by investigators to determine abrasion-erosion resistance of a concrete surface. Among these are the rubbing types of apparatus, dressing wheel, shot-blast, rolling steel balls under pressure, and modified Los Angeles rattler.

5. The two common methods of achieving the rubbing action are either a reciprocating disk or a revolving disk with some sort of abrasive material, usually carborundum, silica sand, or slag (Kennedy and Prior 1953). The length of time required to obtain significant results depends mainly on the abrasive material used, the pressure applied, and the speed of operation. Figures 2 and 3 illustrate a reciprocating-type

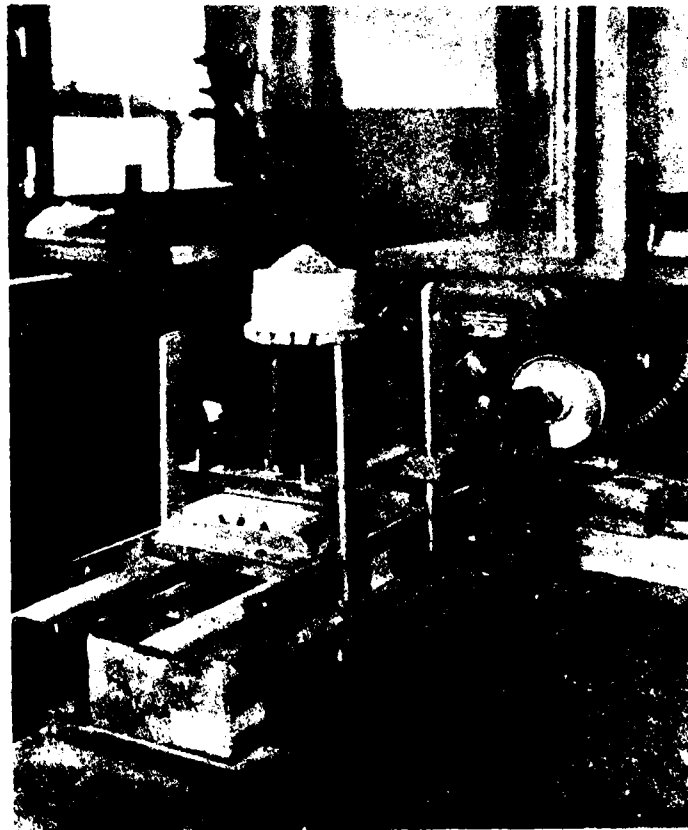


Figure 2. Reciprocating abrasive machine developed by Research Laboratories, Public Service Gas and Electric Co.

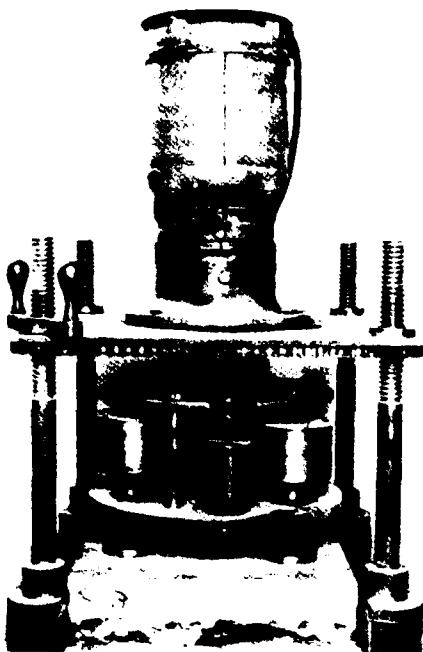


Figure 3. Revolving disks abrasion test machine

machine and a revolving disk-type machine, respectively. In general, if only a surface hardness is to be examined, the rubbing-type machines will produce satisfactory results. When the surface wears off, the abrasive disk will then proceed to ride on the hardest piece of aggregate. In the stilling basin, however, the waterborne particles will erode around the harder particles, leaving them protruding and susceptible to impact. Therefore, the rubbing-type tests are not suitable for evaluating the abrasion-erosion resistance of concrete in the stilling basin.

6. A typical dressing-wheel type apparatus is shown in Figure 4. It is, in general, much more rapid in action than the rubbing-type machine and is a fairly simple piece of equipment. It can be set up in a drill press and does not require an abrasive material. General practice is to clean the surface occasionally during the test by blowing the dust off the specimen under test. When the wear caused by the wheel has progressed through the surface of the concrete, there is again a tendency for the hardest aggregate particles to carry the burden. However, this condition is not so pronounced with the dressing wheel as with the rubbing tests, because some of the teeth will be making contact at other points.

7. The shot-blast test (Figure 5) has also been used for abrasion tests. As previously stated, after the stilling basin floor surface has been eroded away, the waterborne abrasives tend to cut the weaker portion of the concrete, which usually is the mortar, and destroy the bond of the aggregate, thus releasing it from the mass. The shot-blast can duplicate this action. The trouble with the shot-blast method is that

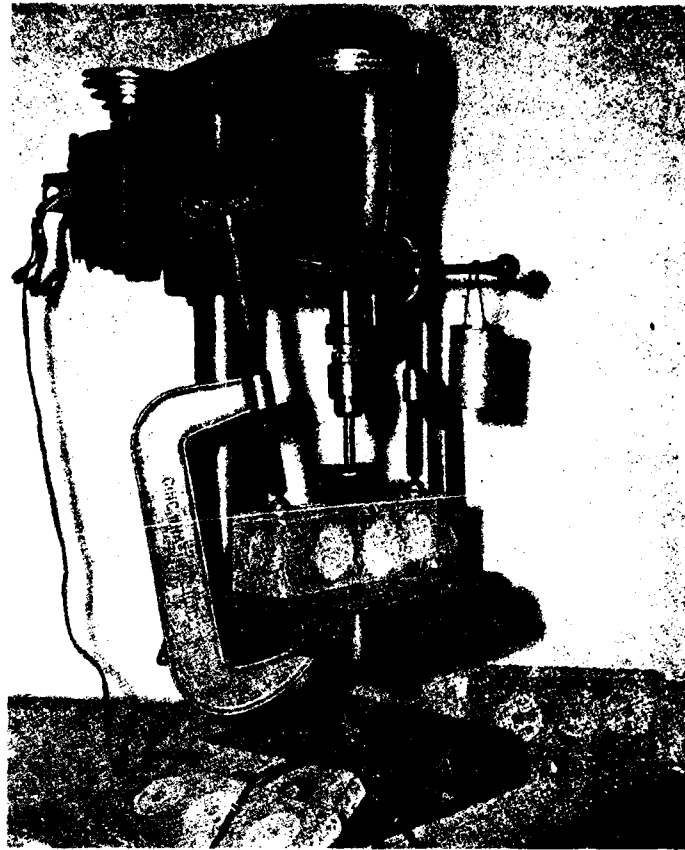


Figure 4. Typical drill press setup for dressing wheel type of testing

a uniform grading and flow of shot is difficult to maintain.

8. Several methods involving balls, shoes, and rolls have been used experimentally with varying degrees of success (Kennedy and Prior 1953). One of these, a ball-bearing method, develops wear by rolling steel grinding balls under pressure over the surface of the concrete (Figure 6). The surface of the concrete is subjected to flowing water to wash the abraded material off as it is produced. This apparatus is rather bulky and costly, factors that are a disadvantage to the method.

9. Another method of determining abrasion resistance involves a modification of the Los Angeles rattler (Scofield 1975). Concrete cylinders or cubes are placed in the machine and tumbled for various periods of time. The abrasion resistance is then determined by visual

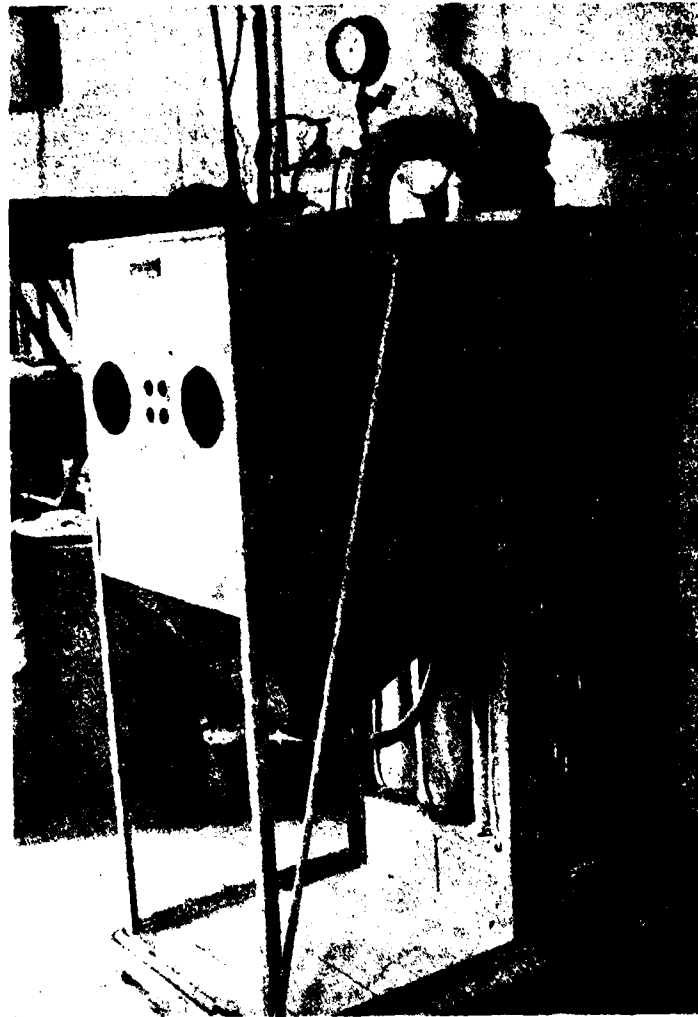


Figure 5. Typical shot-blast test cabinet

observation and determination of weight loss. A hard, brittle concrete might break up in this test, and a softer material might stand up. In actual conditions, however, the harder concrete would resist abrasive forces much better than the relatively softer material. Hence, this method is not well suited for the determination of abrasion resistance.

10. As discussed above, none of the existing test methods are satisfactory for evaluating the resistance of concrete subjected to the abrasive action of waterborne particles in a stilling basin. A new



Figure 6. Ball-bearing abrasion test machine

underwater abrasion test method was therefore devised. The apparatus consists of essentially a drill press, an agitation paddle\* (Figure 7), a cylindrical steel container that houses a disk-shaped concrete specimen, and 70 steel grinding balls of various sizes (ten 1-in.-diameter balls, thirty-five 0.75-in.-diameter balls, and twenty-five 0.50-in.-diameter balls). The steel grinding balls simulate the abrasive changes in the stilling basin (Figure 8). The overall test setup and a detailed cross-sectional view are given in Figures 9 and 10, respectively.

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\* Model PS-21 manufactured by the Jiffy Mixer Company, Inc., 17981 Sky Park Circle, Suite G, Irvine, California 92714.

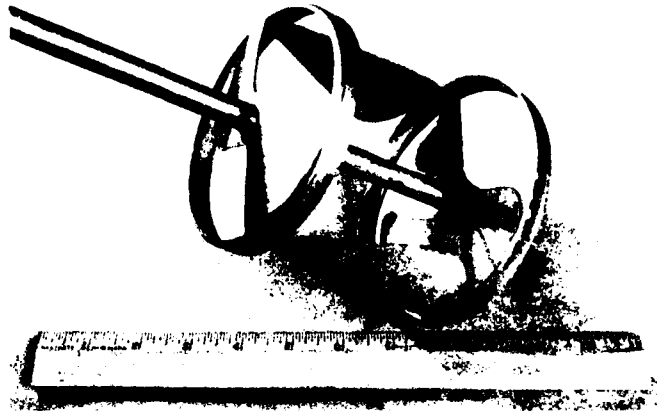


Figure 7. Agitation paddle

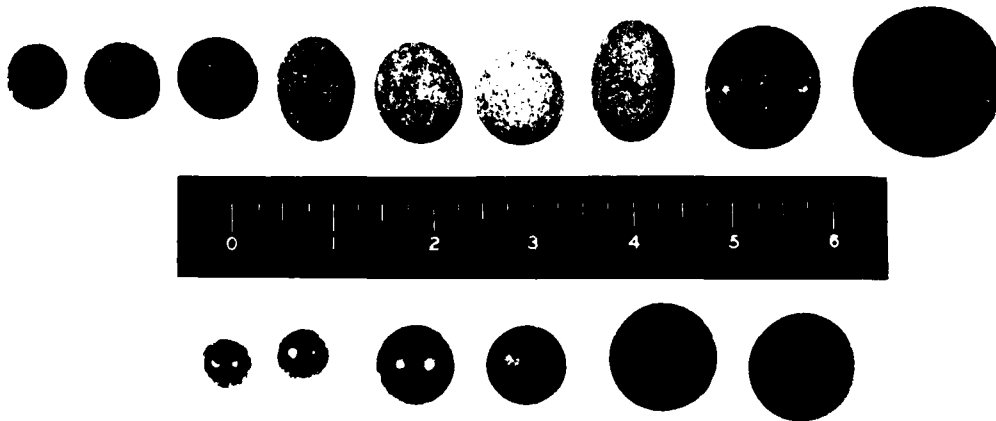


Figure 8. Steel grinding balls and typical rocks obtained from a stilling basin

11. The water in the container is circulated by the immersed agitation paddle that is powered by the drill press rotating at approximately 1200 rpm. The circulating water, in turn, moves the abrasive charges (steel grinding balls) on the surface of the concrete specimen, producing the abrasion effects. The average water velocity on the surface of the specimen as measured by a blunt-nose pitot tube is approximately 6 ft/sec. This new abrasion-erosion test method can duplicate

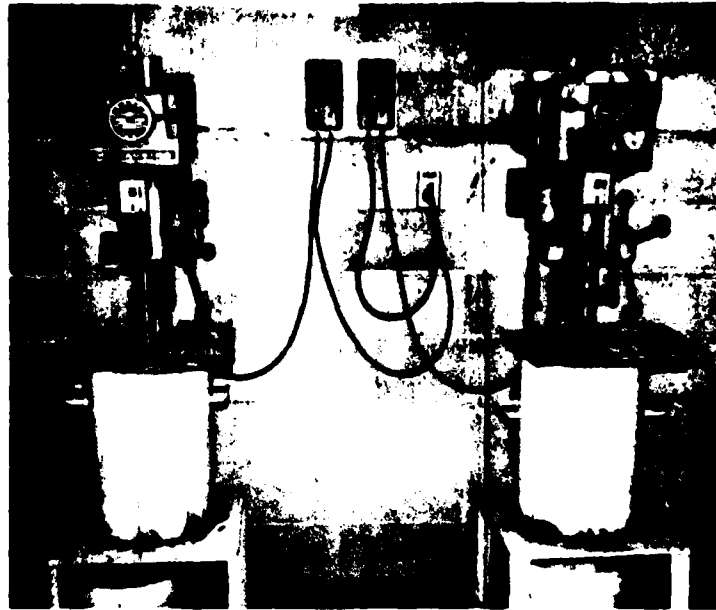


Figure 9. Test setup, overall view

well the abrasive action of waterborne particles in the stilling basins. As can be seen from Figure 11, the surface conditions of the tested specimens are very similar to the eroded concrete surfaces observed in the stilling basins. This method is not, however, intended to provide a quantitative measurement of the length of service that may be expected from a specific concrete. It can be used to determine the relative resistance of a material to the abrasive action of waterborne particles.

12. The test procedures used in this test program were as follows:

- a. Surface dry the specimen with compressed air.
- b. Weigh and record the mass of the specimen.
- c. Place specimen in the steel container with the surface to be tested facing up.
- d. Position the specimen so that the surface of the specimen is normal to the drill shaft and the center of the specimen coincides with the drill shaft.
- e. Mount the agitation paddle in the drill press. The bottom of the agitation paddle is approximately 1-1/2 in. above the surface of the specimen.

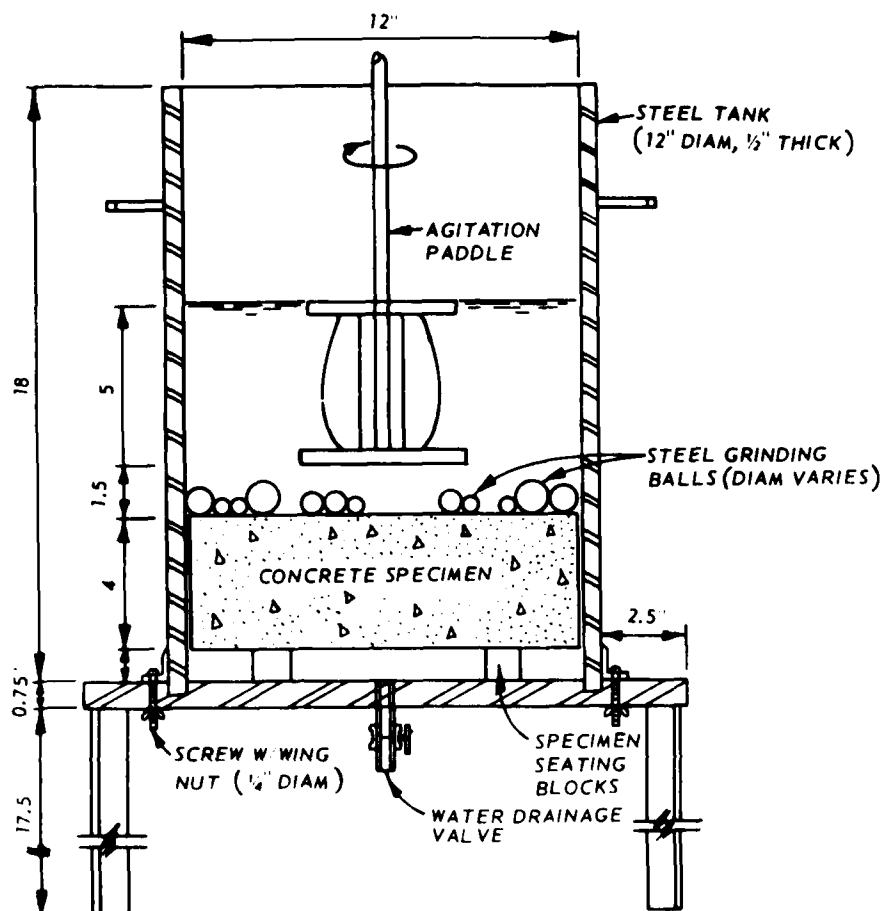
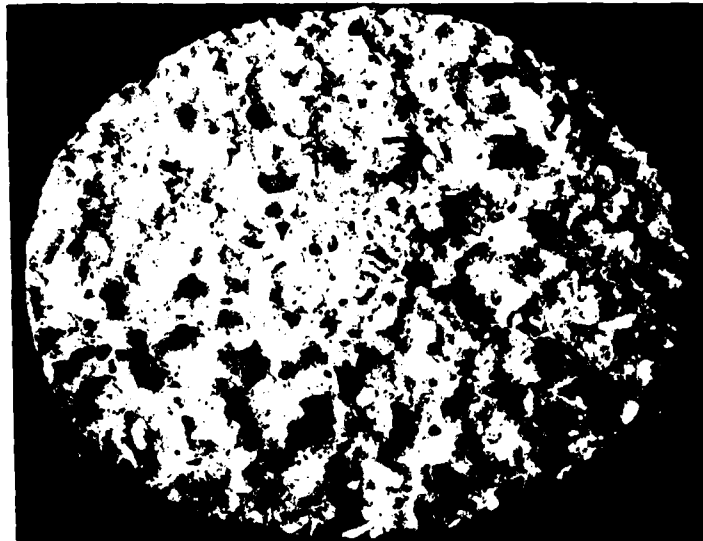
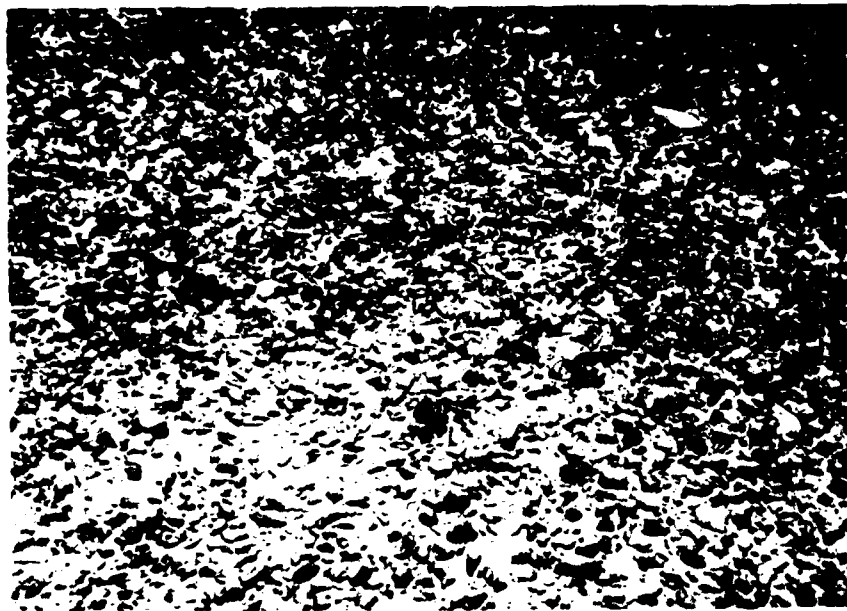


Figure 10. Test setup details

- f. Place the abrasive charges on the surface of the specimen and add water to approximately 6-1/2 in. above the surface of the specimen.
- g. Set the drill press at 1200 rpm and start the machine. A test period of 24 hr generally produces significant abrasion-erosion in most concrete surfaces. However, in this test program, all specimens were tested for 72 hr.
- h. At 12-hr intervals, remove the specimen from the container. Flush off the abraded material, surface dry the specimen, and weigh and record the mass.



a. Typical surface condition of a tested specimen



b. Eroded stilling basin surface at Arkabutla Dam

Figure 11. Typical surface conditions on a tested specimen and the eroded stilling basin floor

13. The abrasion-erosion loss is calculated by the following equation

$$L = \frac{M_i - M_f}{M_i} \times 100 \quad (1)$$

where

L = abrasion-erosion loss, percent by mass

$M_i$  = mass of the surface-dry specimen before test, lb

$M_f$  = mass of the surface-dry specimen after test, lb

14. The percent loss by mass is only of importance for comparison in this investigation. Had the specimens been of greater thickness, the amount of eroded material would have remained the same, but the abrasion-erosion loss in percent would have decreased.

### PART III: TEST PROGRAM

15. The test program was designed to evaluate the relative abrasion-erosion resistance of various materials considered for use in the repair and construction of concrete structures subject to such damage. It encompassed three concrete types (conventional concrete, fiber-reinforced concrete, and polymer concrete); seven aggregate types (limestone, chert, trap rock, quartzite, granite, siliceous gravel, and slag); three principal water-cement ratios (0.72, 0.54, and 0.40); and six types of surface treatment (vacuum, polyurethane coating, acrylic mortar, epoxy mortar, furan resin mortar, and iron aggregate topping). A total of 114 specimens made from 41 batches of concrete was tested. The detailed test program is summarized in Table 1.

#### Materials

##### Cement

16. An American Society for Testing and Materials (ASTM) Type I portland cement (ASTM C 150-78)\* was used. The complete cement analysis is given in Appendix A.

##### Aggregates

17. A total of seven different types of aggregates were used in this investigation. A general petrographic description of these aggregates is as follows.

- a. Limestone - this rock is fine-grained and ranges in composition from dolomitic limestone to calcitic dolomite. Since it is free of cherty or shaly zones, it is essentially all calcite and dolomite. The average Mohs hardness is approximately 3.5.
- b. Chert - this material is about one half dense brown chert and one half porous white chert. The mineralogical

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\* The ASTM standards referred to in this report carry the C and D designations ("Cementitious, Ceramic, Concrete, and Masonry Materials" and "Miscellaneous Materials," respectively). The individual methods will be cited as they occur; however, no individual standards will be included in the References. The reader is referred to the 1979 Annual Book of ASTM Standards.

composition is all quartz. The average hardness is about 6.6.

- c. Trap rock - the dark rock is mostly plagioclase feldspar with smaller amounts of magnetite, clays, and quartz. The magnetite content is high enough that most pieces are strongly magnetic. The reddish rock is mostly quartz and plagioclase and potassium feldspars with smaller amounts of clays, calcite, and the iron oxide minerals hematite and magnetite. The average Mohs hardness of the trap rock is estimated to be 6.4.
- d. Quartzite - this rock is a well-known pre-Cambrian Age orthoquartzite which would be termed a quartz arenite by the newer terminology. It is almost entirely quartz and should have a Mohs hardness of 7. The white powdery material partially coating particle surfaces is a mixture of kaolinite clay, quartz, and a little mica and calcite.
- e. Siliceous gravel - this material was used for the construction of Libby Dam and was furnished to WES by the U. S. Army Engineer District, Seattle. This material is said to be about 60 percent quartz, 30 percent argillite, and 10 percent limestone and miscellaneous other rock types. The average Mohs hardness is about 6.1.
- f. Granite - coarse aggregate was subround to subangular particles with less than 2 percent flat and/or elongated particles. The aggregate was generally crushed and had 5.3 percent soft particles and 1.4 percent friable particles. The rock was predominantly granitic with a small percentage of andesite, meta-granite, and quartzite. The granitic rock varied in composition from granite to granodiorite. Individual particles were fresh to moderately weathered.
- g. Slag - individual particles of the processed, air-cooled, blast furnace slag were vesicular, moderately hard, and irregularly shaped. Almost 30 percent of the particles had less than 2.00 specific gravity. The slag was almost entirely light to medium gray in color with only a trace of the black or conglomeratic particles. The slag was generally composed of a glassy matrix in which small crystals were present. The percentage of glass to crystalline material varied from particle to particle. Most of the crystals were members of the metilite series composed of akermanite, gehlenite, and metilite. No breaking occurred to any of the slag particles during the wetting and drying test.

18. Pertinent physical characteristics of the aggregates are given in Appendix A.

#### Steel fibers

19. Four different types of steel fibers were used; two straight fibers and two hooked fibers. The nominal sizes of the straight steel fibers were 0.010 by 0.020 by 1 in. and 0.010 by 0.020 by 0.5 in. The nominal sizes of the hooked fibers were 2.0 by 0.02 in. and 1.2 by 0.015 in.

#### Monomer system

20. The monomer system used for polymer-impregnated concrete (Batch M1) was as follows:

- a. Monomer - methyl methacrylate (MMA) inhibited with 25 ppm HQ.
- b. Cross linking agent - Trimethylpropane trimethacrylate (TMPTMA).
- c. Initiator - VAZO 64.

21. These materials were formulated for ambient conditions and polymerization was achieved by addition of heat.

22. The monomer system used for methyl methacrylate polymer concrete (Batch M4) consisted of the following:

- a. Monomer - MMA.
- b. Cross linking agent - TMPTMA.
- c. Initiator - Benzoyl Peroxide-70 (BP-70).
- d. Promoters - N,N-dimethyl aniline (DMA) and N,N-dimethyl-p-toluidine (DMT).

23. The monomer system used for vinyl ester polymer concrete (Batch M5) was as follows:

- a. Monomer - Vinyl ester resin containing 36 percent styrene by mass.
- b. Catalyst - Methyl ethyl ketone peroxide (MEKP).
- c. Promoters - Cobalt and naphthanate (CON) and N,N-dimethyl aniline (DMA).

#### Epoxy resin system

24. The epoxy resin system used in making the polymer portland cement concrete (Batch M2) is a two-component, water-dispersible epoxy system. The typical properties (at 75°F) of the epoxy system are as follows.

Property	Epoxy Resin
Color, Part A	Amber
Part B	Amber
Mixing Ratio	1:1
Viscosity	
Part A	700-800 cps
Part B	200-300 cps
Mixed (Part A + Part B)	400-600 cps
Thixotropic Index	1.48
Pot Life	2-3 hr
Initial Cure	24 hr
Tensile Strength	1300 psi minimum
Compressive Strength	7500 psi minimum
Concrete Bond Strength	
(Direct shear)	500-800 psi
Flexural Stength (psi)	1800 minimum
Fire Rating	Same as concrete
Coefficient of thermal expansion	$5.7 \times 10^{-5}$ in./in./°F
Chemical Resistance	Excellent to all common inorganic acids, organic acids, alkalis, solvents, etc.

#### Polyurethane

25. Two types of elastomeric polyurethane systems were investigated: T19 and T21.

- a. The T19 specimens were coated with two coats of base polyurethane coating and three coats of top polyurethane coating. These coatings are one component, approximately 100 percent solid elastomeric urethane system, which cures by moisture in the air. The base coating has good adhesive properties and the top coating has better weathering and abrasion resistance. The typical physical properties are as follows.

Property	Base Coating	Top Coating
Solid Content	90% $\pm$ 2%	63%
Cure Time (77°F, 50% RH)	40 mils-30 hr	10 mils-36 hr
Hardness (Shore A)	60	97
Tensile Strength (ASTM D 412-75)	300 psi	3500 psi

(Continued)

<u>Property</u>	<u>Base Coating</u>	<u>Top Coating</u>
Elongation (ASTM D 412-75)	500%	175%
Adhesion to Concrete (ASTM D 903-49)	20 pli	
Tear Resistance (ASTM D 1004-66)	130 pli	

- b. The T21 specimens were coated with a two-component polyurethane system. The mixing ratio of the two components is 1 to 1 by volume. The typical performance properties (cures 24 hr at 75°F plus 24 hr at 120°F) are as follows.

<u>Property</u>	<u>Polyurethane Coating</u>
Hardness (Shore A)	80
Specific Gravity (Cured)	1.06
Tensile Strength (ASTM D 412-75)	2500 psi
Elongation (ASTM D 412-75)	300%
Tear Strength, Die C (ASTM D 412-75)	300 pli

#### Acrylic mortar

26. The acrylic mortar is a two-component system. One component is the resin (a powder mixture of 80 percent quartz-sand, sized 0 to 1.5 mm, and 20 percent Benzoyl peroxide powder), and the other component the hardener. The two components are mixed in proportion 7.5:1 powder resin to hardener by weight.

#### Epoxy resin mortar

27. Two epoxy resin systems used in making the epoxy resin mortars were investigated. One epoxy resin was a low modulus, and the other was a high modulus. Both epoxies were two-component, 100 percent solid, moisture-insensitive epoxy resins. The mixing ratios of the components "A" to "B" are 2 to 1 and 1-1/2 to 1 by volume for the low modulus and high modulus, respectively.

28. Neither of the two epoxy resin systems will meet the requirements of CRD-C 590-74 and CRD-C 591-73 (WES 1949). The low modulus epoxy resin system does meet the requirements of ASTM C 881-78, "Standard

Specification for Epoxy-Resin-Base Bonding Systems for Concrete"; however, the high modulus does not meet the requirements of this specification because of shrinkage.

29. The epoxy resin mortars consist of one part epoxy resin to four parts graded Ottawa sand by volume for the low modulus epoxy resin, and one part epoxy resin to three parts graded Ottawa sand by volume for the high modulus epoxy resin. The properties of the neat epoxy resin binder and mortars are as follows.

<u>Neat Epoxy Binder</u>	<u>Low Modulus</u>	<u>High Modulus</u>
Tensile Strength (ASTM D 638, ASTM 1977)	2,000 psi @ 14 days, 75°F	3,200 psi @ 14 days, 75°F
Tensile Elongation (ASTM D 638, ASTM 1977)	13% @ 14 days, 75°F	1% @ 14 days, 75°F
Compressive Strength (ASTM D 695, ASTM 1977)	5,000 psi @ 28 days, 75°F	12,000 psi @ 14 days, 75°F
Compressive Modulus	175,000 psi @ 28 days, 75°F	400,000 psi @ 28 days, 75°F
Viscosity (at 75°F)	700 cps	2200 cps
Gel time (at 75°F)	40 min	40 min
<u>Mortar</u>		
Compressive Strength (ASTM C 109-77)	7,200 psi @ 28 days, 75°F	12,000 psi @ 28 days, 75°F
Compressive Modulus (ASTM C 109-77)	850,000 psi @ 28 days, 75°F	1,250,000 psi @ 28 days, 75°F

#### Furan resin mortar

30. The resin is a furfuryl alcohol polymer with a viscosity of about 450 cps at 25°C. The catalyst used to polymerize the resin is an organic acid. The mixing ratio of the resin to catalyst is 100 to 5 by mass. The furan resin mortar consists of three parts of graded Ottawa sand to one part resin by volume. The pot life of the neat resin is 30 minutes at 75°F, and the compressive strength of the furan resin mortar is 8500 psi. No other physical properties of the neat resin or polymer mortar were measured, and no physical properties were available from the manufacturer.

#### Iron aggregate topping

31. The iron aggregate topping is composed of the following blended ingredients.

- a. Iron aggregate, from very fine particles to iron slivers 0.40 in. long, maximum. The particles are graded to produce an optimum iron aggregate concrete upon mixing with water.
- b. ASTM Type II cement (ASTM C 150-78).
- c. A water-reducing admixture in powder form.

32. The color of the iron aggregate topping before it is mixed is dark gray, similar to normal portland cement concrete. After mixing and in place, the color is a grayish black, considerably darker than normal concrete.

#### Concrete mixtures

33. The concrete mixtures used in the test specimens are summarized in Table 2, and mixture proportions are given in Appendix A.

#### Specimen Fabrication

34. The concrete was mixed in a laboratory 7.5-cu-ft rocking and tilting drum mixer in 5-cu-ft batches.\* Each batch was tested for slump and air content according to CRD C 5-76 and CRD C 8-79 (WES 1949), respectively.

35. Four 11-3/4-in. diameter by 4-in.-high specimens were cast in specially designed molds (Figure 12). In addition to the abrasion specimens, three 6- by 12-in. cylinders and three 6- by 6- by 36-in. beams were cast for compressive strength and flexural strength tests, respectively. The concrete was placed in the mold using a scoop and consolidated on a vibrating table. The surface was finished by screeding and floating approximately 15 minutes after vibration, and final steel troweling was done approximately 3 hr after vibration. After 24 hr in the fog room, the specimens were demolded and placed in the tank of

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\* Batches F9 and M3 were made at Libby Dam during the repair of its stilling basin.



Figure 12. Mold for test specimen

lime-saturated water until test. All specimens were water cured for at least 28 days prior to testing. The cylinders and beams were cured in the same manner as the abrasion test specimens. Figure 13 shows a typical untested specimen.

36. The procedures used for fabricating polymer concrete specimens and for application of surface treatments are as follows.

Polymer-impregnated concrete (PIC)

37. The procedures used for polymerization of M1 specimens were as follows.

- a. The test specimens were placed in a drying oven at 260°F and dried for 24 hr.
- b. The specimens were allowed to cool to room temperature in a closed container containing a desiccant to remove moisture.
- c. The following day, the specimens were impregnated with the polymer using the procedures below:
  - (1) Adhesive tape was applied around the perimeter of the specimen surface to be polymerized to form a reservoir approximately 1/2 in. deep.

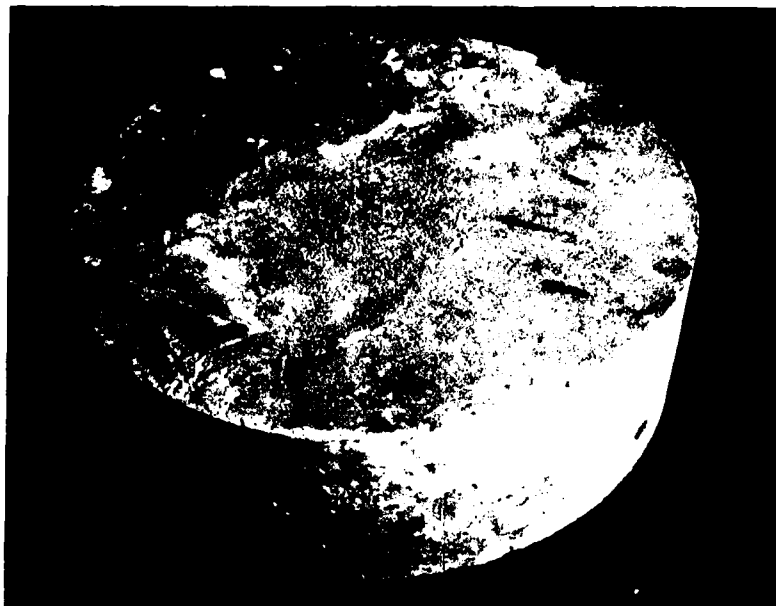


Figure 13. Typical untested specimen

- (2) Dried sand was then placed approximately 1/4 in. deep on the surface.
- (3) The monomer system containing 97 percent methyl methacrylate; 2.5 percent cross linking agent, tri-methyl propane trimethacrylate (TMPTMA); and 0.5 percent catalyst, VAZO 64, was sprinkled over the sanded area until the surface contained the ponded solution above the sand.
- (4) Subsequent applications of the monomer system were made to the surface to keep it full of the liquid monomer. Between applications of the monomer the wet surface was covered with a polyethylene sheet to minimize evaporation. The monomer system was allowed to soak into concrete for approximately 5 hr.
- (5) The tape was removed from the impregnated specimens, and the specimens were wrapped with aluminum foil to minimize evaporation. Sand darkened with carbon black was placed on the top of the aluminum foil that covered the impregnated surfaces. The surfaces were then heated for 1-1/2 hr using infrared lamps.

38. The M3 specimens were fabricated by the Seattle District. The procedures used for M3 specimens were similar to those used for

polymerization of fiber-reinforced concrete for stilling basin repair at Libby Dam.\*

Polymer portland  
cement concrete (PPCC)

39. The cement was placed first into the concrete mixer and approximately 90 percent of the water added. The two ingredients were then mixed for about 5 minutes until the cement had wetted thoroughly. The coarse and fine aggregates along with the epoxy were then added into the mixer and mixed for a few minutes. The remaining water was then added and the PPCC mixed until all particles were wetted. It was noted that the PPCC tended to stick to the sides of the mixer and had to be scraped off during mixing.

Methyl methacrylate polymer concrete

40. The following methyl methacrylate (MMA) formulation was used in making the polymer concrete (Batch M4).

Aggregate concentration**	85 percent by mass
Monomer (95 percent MMA by weight and 5 percent TMPTMA by weight)	15 percent by mass
Initiator concentration	3 percent BP-70 by mass of monomer
Promoter concentration	1 percent DMA and 1 percent DMT, both by mass of monomer

41. The monomer consisting of MMA and TMPTMA was mixed for about 5 minutes. The promoters (DMA and DMT) and the initiator (BP-70) were then mixed into the monomer system until all the BP-70 had dissolved.

42. The required amount of clean and dried aggregate was placed in a mixer. With the mixer containing the aggregate running, the

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\* Munch, A. V. and Oedewaldt, R. M. "Polymerization of Fibrous Concrete for Stilling Basin Repair at Libby Dam (unpublished)," Libby Dam Resident Office, CE, Libby, Mont.

\*\* The aggregate was made up of 2 parts of fine aggregate and 1 part of coarse aggregate, by mass (maximum aggregate size = 3/8 in.).

monomer mixture was poured onto the aggregate in the mixer, and the mixing continued until all the aggregate was wetted. This normally takes only about 3 minutes. After mixing, the polymer concrete (PC) was placed on the surface of the specimen to be coated. The PC overlay was then smoothed with a trowel.

#### Vinyl ester polymer concrete

43. The composition of the vinyl ester polymer concrete (Batch M5) is as follows:

Aggregate concentration	86 percent by mass
Monomer (vinyl ester resin)	14 percent by mass
Catalyst	1 percent MEKP by mass of monomer
Promoters	0.2 percent CON and 0.05 percent DMA, by mass of monomer

44. The limestone aggregate used was made up of 2 parts by mass of fine aggregate and 1 part by mass of coarse aggregate (3/8-in. maximum aggregate size).

45. The vinyl ester resin system was divided into equal batches before preparing the polymer concrete and was identified as Parts A and B. The required amount of MEKP was dissolved into Part A, and the CON and DMA dissolved into Part B. Equal amounts by volume of Part A and Part B were then mixed for priming the concrete surface and making the polymer concrete.

46. The surface of the concrete specimen to be coated was cleaned by sandblasting, washed with water, and dried thoroughly before coating. The monomer system was first prepared by mixing Part A and Part B together. A prime coat of the monomer was applied to the surface to be coated before the polymer concrete overlay was placed. The procedures for mixing and placing of vinyl ester polymer concrete overlay were the same as those for methyl methacrylate polymer concrete.

#### Vacuum treatment

47. The fresh concrete in the mold was vibrated on the vibrating

table and lightly trowelled before the vacuum dewatering process was begun.

48. A DYNAPAC BA 23 vacuum unit, manufactured by the Dynapac Manufacturing Inc., Stanhope, New Jersey, was used to create suction force (Figure 14).

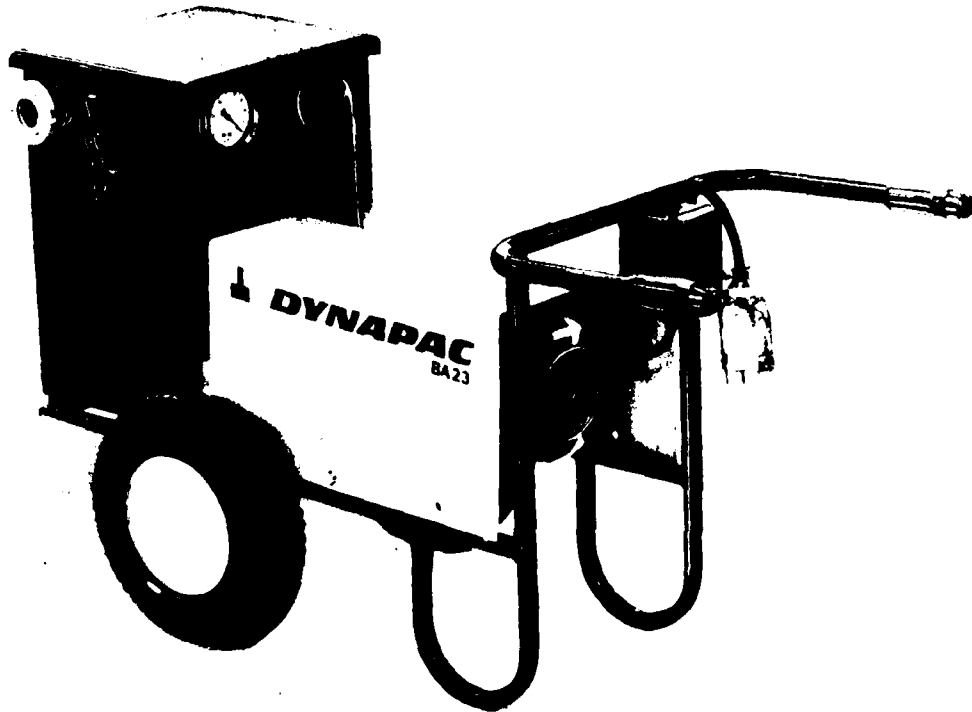


Figure 14. Equipment for vacuum treatment

49. A filter mat was first placed on the wet concrete surface. The filter mat was approximately 11 in. in diameter and consisted of a nylon mesh and a filter cloth. A top vinyl mat was then placed on the top of the filter cloth. The top mat projected slightly beyond the filter cloth on all sides and thus formed a seal against the wet concrete. The top mat was connected to the vacuum pump.

50. The pressure at the mat was between 88 percent to 75 percent vacuum (12.9 psi to 11.0 psi underpressure). This enabled the water on the surface of the concrete under the mat to be sucked into the vacuum system. No measurement was made of the amount of water extracted during

the vacuum process. Figure 15 shows the concrete specimen under treatment. For the 4-in.-thick specimen, the vacuum treatment time was approximately 15 minutes.



Figure 15. Concrete specimen under vacuum treatment

#### Polyurethane coating

51. T19 specimens. The surface of the specimens to be coated was cleaned by sandblasting. The base coat was first applied using a brush. The coating was allowed to cure for 20 hr, then a second coat was applied with a brush. The second coating was allowed to cure for 24 hr. Three coats of top coating were then applied on top of the base coating at 16- to 24-hr intervals between each coat. The coatings were allowed to cure at room temperature (75°F) for 7 days before the specimens were soaked in the lime-saturated water. The thickness of the cured coating was 0.053 in.

52. T21 specimens. The surface of the test specimens to be coated was cleaned by sandblasting. The surface was then coated with a primer using a paint roller. The primer was allowed to cure for 24 hr before coating the specimen with polyurethane. The polyurethane system

was mixed in accordance with the manufacturer's instructions. The coating was applied using an airless sprayer. The desired film thickness was obtained by applying seven coats of the material with a 5- to 10-minute wait between coats. A dry film thickness of 0.07 in. was obtained on the test specimens.

#### Acrylic mortar coating

53. The surface of the test specimens to be coated was cleaned by sandblasting. The resin and the hardener were machine-mixed for 3 minutes then trowelled on top of the cleaned specimens to a thickness of approximately 3/8 in. The acrylic mortar started to stiffen about 10 minutes after mixing and was hard after 1 hr.

#### Furan resin mortar

54. The furfuryl alcohol was first mixed in a plastic container using a jiffy mixer. The surface of the specimen was cleaned and coated with a thin film of the furfuryl alcohol resin using a paint roller. The mixed furfuryl alcohol resin was then transferred to a dough mixer and the sand added during mixing. The furfuryl alcohol resin mortar was then trowelled on the prepared surface of the specimens. The thickness of the furan resin mortar was approximately 3/8 in.

#### Iron aggregate topping

55. The surfaces of the test specimens to be coated were cleaned by sandblasting. Approximately 0.55 gal of water was added to the 55 lb of blended ingredients (iron aggregate, Type II cement, and a water-reducing admixture in powder form) and mixed thoroughly in a mixer. The mortar was then trowelled on top of the cleaned specimens to a thickness of approximately 1 in.

#### PART IV: TEST RESULTS AND DISCUSSION

56. The abrasion-erosion test results are presented in Table 3 and are summarized in Table 1. The photographic record of the typical concrete surface conditions after 72 hr of testing is given in Appendix B.

57. This study, as previously stated, was composed of 41 batches of concrete. In one or more of these batches, the effects of (a) water-cement ratio, (b) compressive strength, (c) aggregate type, (d) concrete type, and (e) type of surface treatment, on abrasion-erosion resistance of concrete can be evaluated.

##### Effects of Water-Cement Ratio

58. The effects of water-cement ratio on abrasion-erosion resistance of concrete can be seen from Figures 16 through 19, where average abrasion-erosion losses, percent by mass, of conventional concrete are plotted against test time. A reduction in water-cement ratio from 0.72

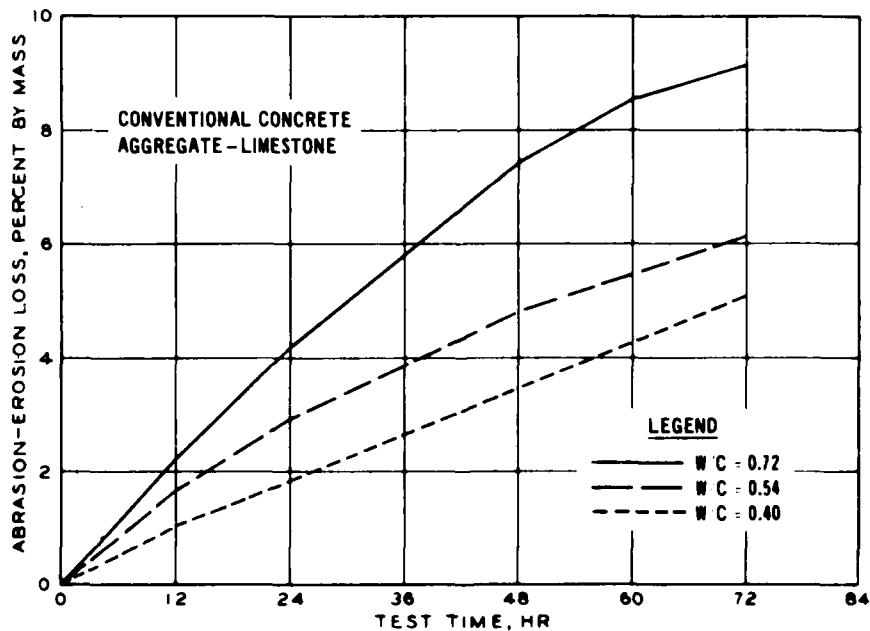


Figure 16. Effects of water-cement ratio on abrasion-erosion resistance of concrete containing limestone aggregate

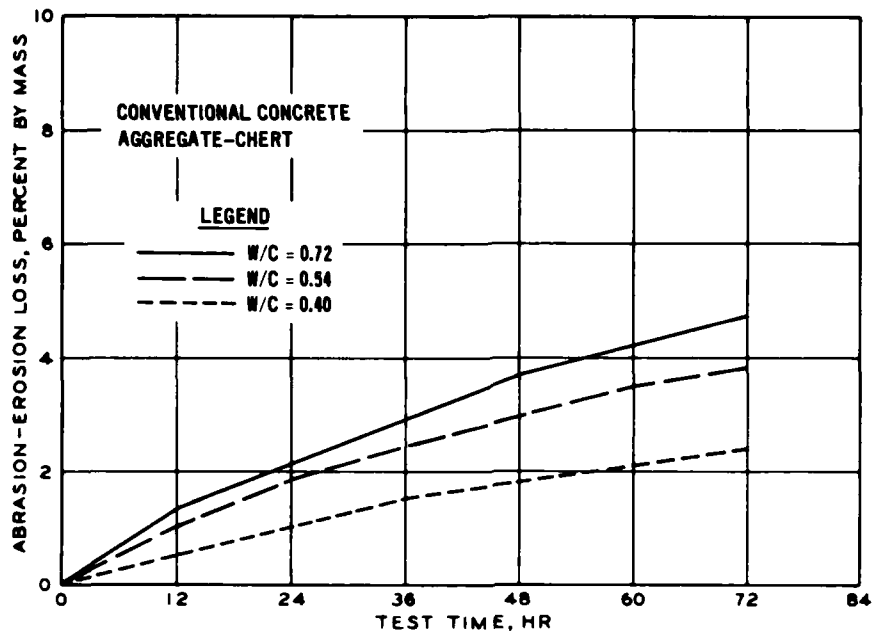


Figure 17. Effects of water-cement ratio on abrasion-erosion resistance of concrete containing chert aggregate

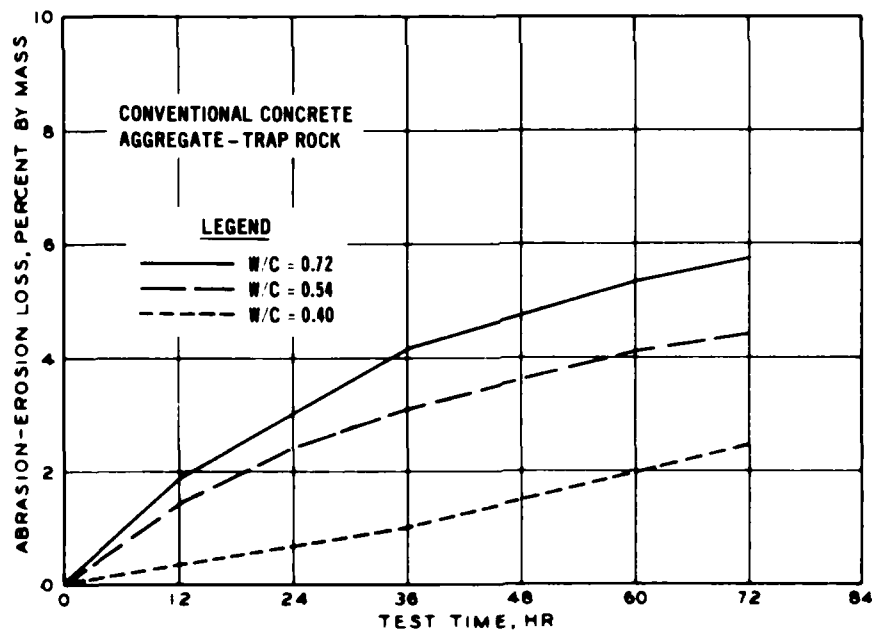


Figure 18. Effects of water-cement ratio on abrasion-erosion resistance of concrete containing trap rock aggregate

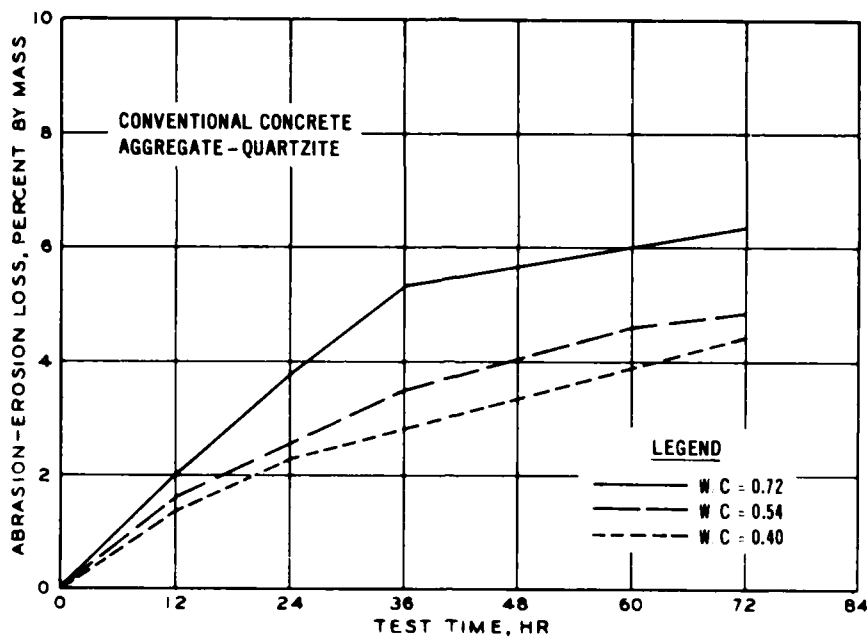


Figure 19. Effect of water-cement ratio on abrasion-erosion resistance of concrete containing quartzite aggregate

to 0.40 resulted in approximately 43 percent, 48 percent, 56 percent, and 30 percent improvement in abrasion-erosion resistance (the reciprocal of abrasion-erosion loss) at 72 hr for concrete containing limestone, chert, trap rock, and quartzite, respectively.

59. A similar relationship between water-cement ratio and abrasion-erosion resistance was also evident for fiber-reinforced concrete (Figures 20 and 21). In these cases, approximately 41 percent and 38 percent improvements in abrasion-erosion resistance were realized for fiber-reinforced concrete containing 1-in. and 0.5-in. straight steel fibers, respectively, when water-cement ratio was reduced from 0.72 to 0.40.

60. Figure 22 plots the average abrasion-erosion loss at 72 hr against water-cement ratio for concrete containing various types of aggregates. This figure clearly indicates that for a given aggregate the abrasion-erosion resistance of concrete increased with decrease in water-cement ratio.

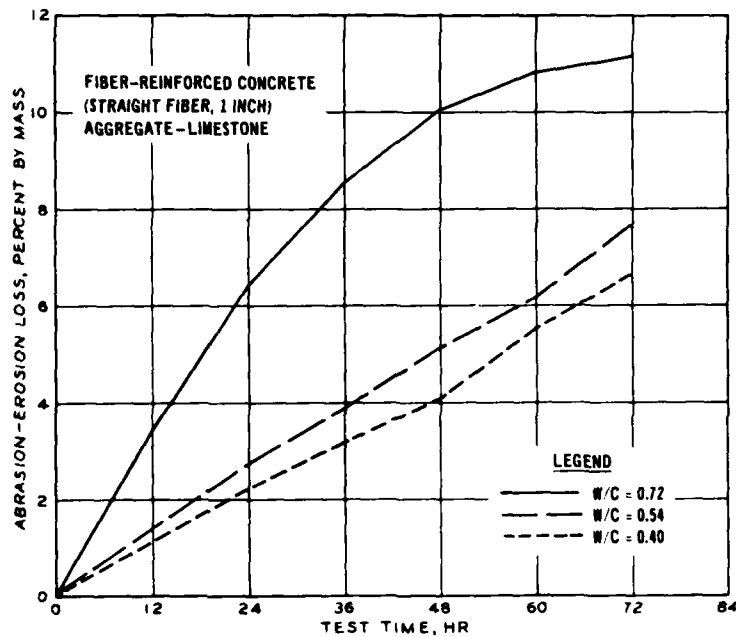


Figure 20. Effects of water-cement ratio on abrasion-erosion resistance of fiber-reinforced concrete, 1-in. straight fiber

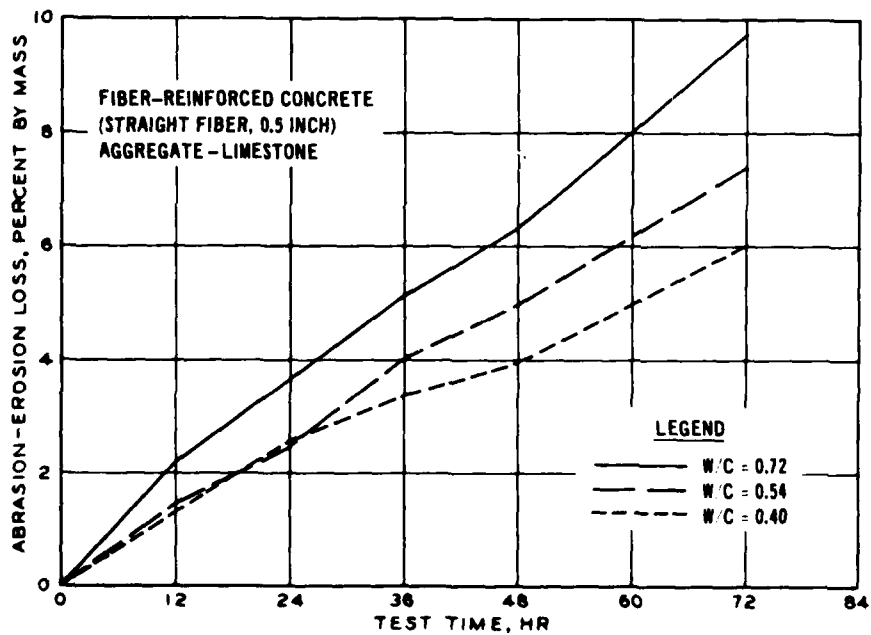


Figure 21. Effects of water-cement ratio on abrasion-erosion resistance of fiber-reinforced concrete, 0.5-in. straight fiber

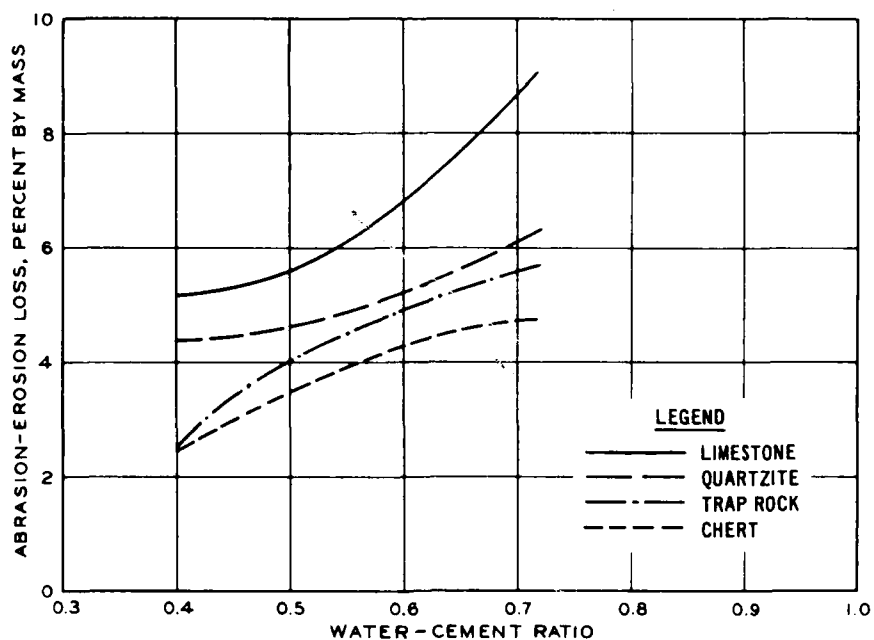


Figure 22. Relationship between water-cement ratio and abrasion-erosion loss

#### Effects of Compressive Strength

61. The abrasion-erosion resistance of concrete having compressive strengths ranging from approximately 3000 psi to 9000 psi was investigated. The relationship between abrasion-erosion loss at 72 hr and compressive strength of conventional concrete and fiber-reinforced concrete is shown in Figures 23 and 24, respectively.

62. These curves indicated that the average abrasion-erosion resistance for both the limestone conventional and fiber-reinforced concrete increased approximately 44 percent as the compressive strength increased from 3000 psi to 9000 psi. These data confirm the findings of other investigators (Kennedy and Prior 1953, Witte and Backstrom 1951, and Smith 1956) who concluded that the abrasion-erosion resistance of concrete increased with increase in compressive strength. However, the relationship is not generally linear. Figures 23 and 24 seemed to indicate that, in general, there was more improvement in abrasion-erosion resistance

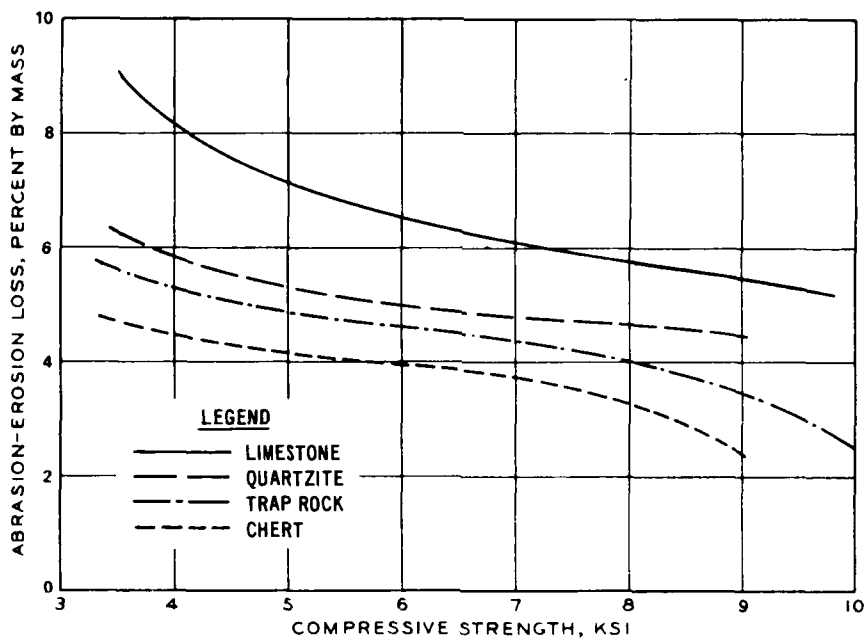


Figure 23. Relationship between abrasion-erosion resistance and compressive strength of conventional concrete

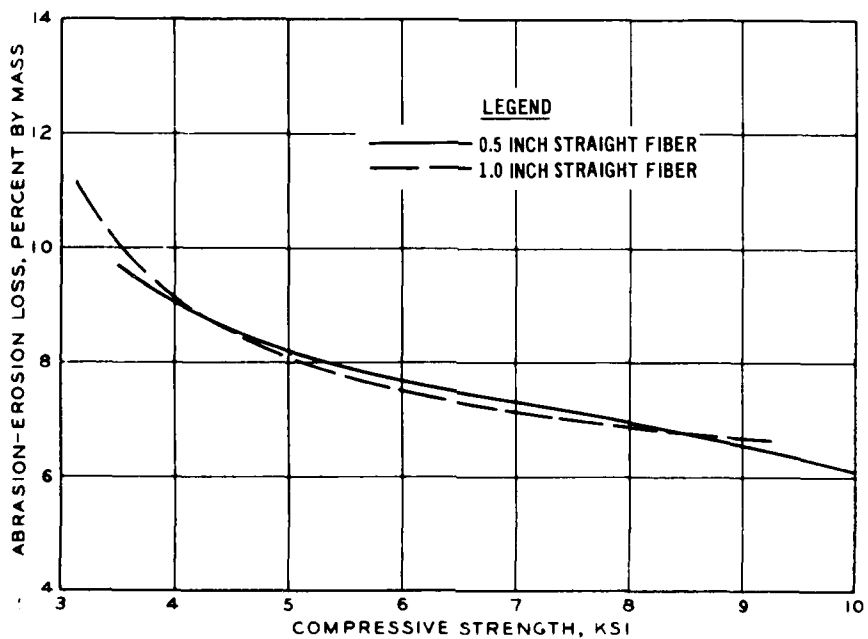


Figure 24. Relationship between abrasion-erosion resistance and compressive strength of fiber-reinforced concrete

by increasing the compressive strength from 3000 psi to 6000 psi, and there appeared to be less advantage to increase the compressive strength above 6000 psi. For example, the abrasion-erosion loss reduced from 10.5 percent to 6.5 percent when the compressive strength of limestone concrete increased from 3000 psi to 6000 psi and reduced only from 6.5 percent to 5.5 percent when the compressive strength increased from 6000 psi to 9000 psi.

#### Effects of Aggregate Type

63. Comparing the results of Batches T1, T4, T7, and T10, each having a water-cement ratio of 0.72, indicated that the type of aggregate has a significant effect on the abrasion-erosion resistance of concrete that contains them (Figure 25). The abrasion-erosion loss of limestone concrete at 72 hr was approximately twice as much as that of the concrete containing chert aggregate. The rate of abrasion-erosion loss in the first 12 hr was generally greater than the remaining test

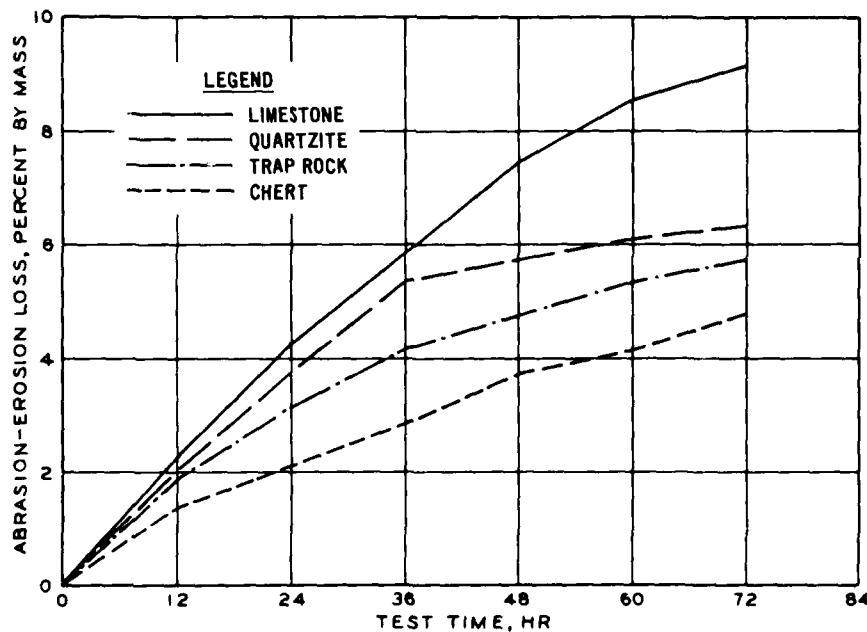


Figure 25. Effects of aggregate type on abrasion-erosion resistance, W/C = 0.72

period because the surface mortar layer is easier to abrade and the rate of abrasion-erosion loss decreases as the mortar layer is worn away and the coarse aggregate is exposed. This behavior was more apparent in concrete containing harder aggregates. For example, for concrete containing chert (Batch T4), approximately 30 percent of the total loss occurred in the first 12 hr and the rate of abrasion reduced to about half for the remaining test period.

64. Figures 26 and 27 show the effects of aggregate type on the abrasion-erosion resistance of concretes with water-cement ratios of 0.54 and 0.40, respectively. The influence of aggregate type on abrasion-erosion resistance of concrete was also clearly indicated.

65. The abrasion-erosion resistance of concretes containing granite and slag (Batches T13 through T16) was compared (Figures 28 and 29). The concrete containing granite had more abrasion-erosion loss during the first 24 hr than the slag concrete. However, the trend was reversed after 24 hr, and the total abrasion-erosion loss of slag concrete at 72 hr was approximately 22 percent and 17 percent higher

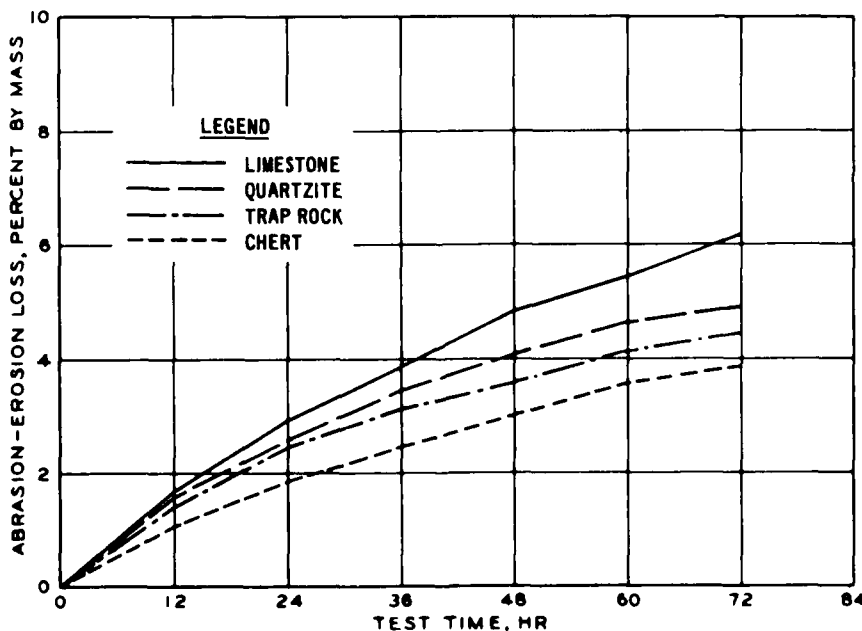


Figure 26. Effects of aggregate type on abrasion-erosion resistance, W/C = 0.54

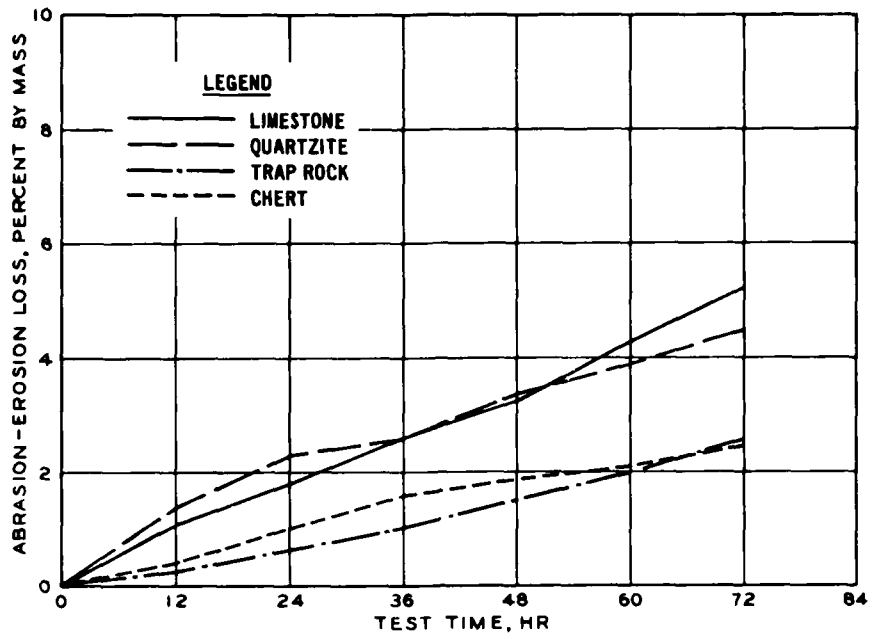


Figure 27. Effects of aggregate type on abrasion-erosion resistance,  $W/C = 0.40$

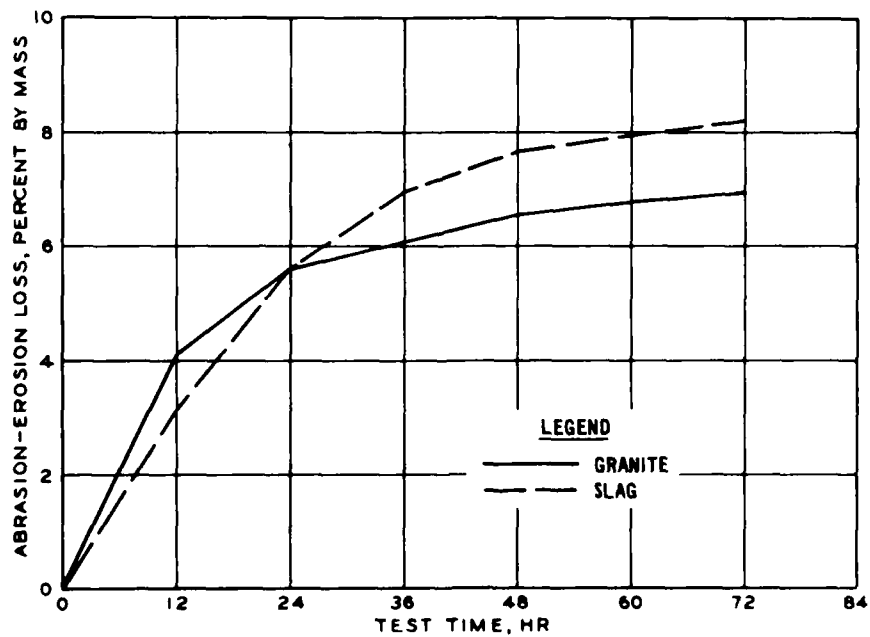


Figure 28. Effects of aggregate type on abrasion-erosion resistance,  $W/C = 0.50$

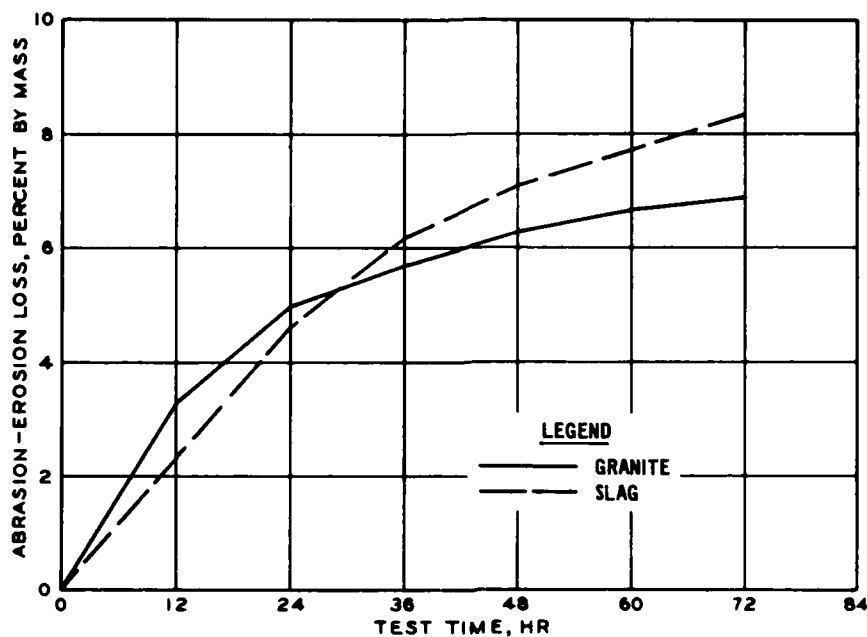


Figure 29. Effects of aggregate type on abrasion-erosion resistance, W/C = 0.55

than that of the concrete containing granite for concretes having water-cement ratios of 0.50 and 0.55, respectively. The vesicular particles of the slag aggregate seemed to have contributed significantly to the abrasion-erosion loss of the slag concrete specimens. The porous nature of these particles is evident in Figures B5 and B6.

66. Figure 30 plots Los Angeles abrasion losses (ASTM C 131-76), at 500 cycles, of various aggregates against the 72-hr abrasion-erosion loss of their various concretes having water-cement ratio of 0.54. Apparently, no relationship existed between the abrasion-erosion resistance of concrete and the resistance of aggregate to abrasion. Los Angeles abrasion losses were approximately equal for soft aggregate such as limestone and relatively hard aggregate, such as chert (Figure 30). However, the abrasion-erosion resistance of the concrete containing these aggregates varied widely, and the limestone concrete was much less resistant than that containing chert. A similar finding was reported by Smith (1956). His explanation for this wide variation lies in the breakdown characteristics

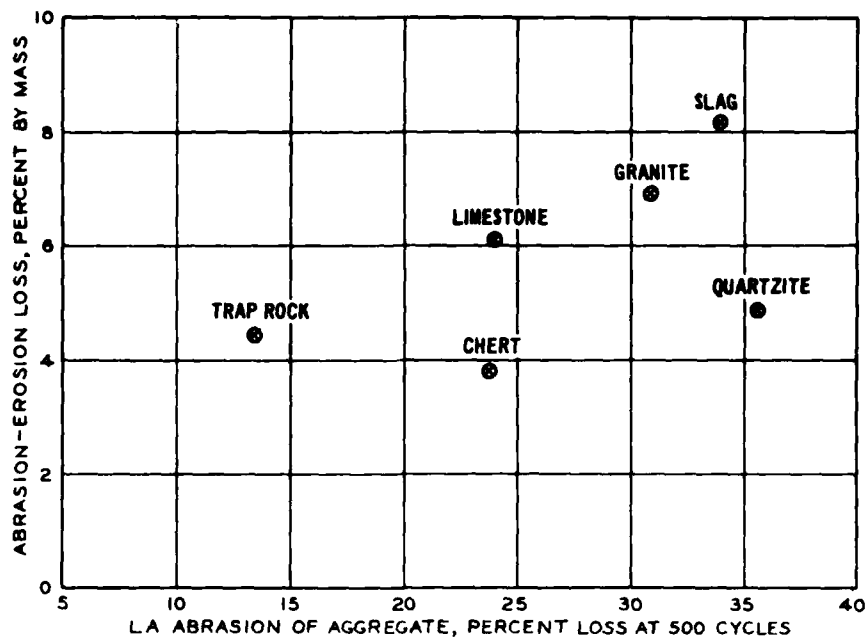


Figure 30. Relationship between resistance of aggregate to abrasion and concrete abrasion-erosion loss

of the different aggregates: the limestone is susceptible to crushing and pulverization, whereas the chert chips and spalls form relatively coarse particles. When concretes containing either of these aggregates are subjected to abrasion-erosion, the film of surface mortar resists the abrasive forces initially, but as the mortar is worn away, the coarse aggregate is exposed. When this condition exists, the softer limestone aggregate is eroded at a greater rate than the chert, thus the limestone concrete has higher abrasion-erosion loss than that of concrete containing chert.

67. The average Mohs hardness values of limestone, trap rock, chert, and quartzite were 3.5, 6.4, 6.6, and 7.0, respectively. Figure 31 plots the Mohs hardness of these aggregates against the abrasion-erosion losses of their concretes. Trends indicated that significant correlation existed between the abrasion-erosion resistance and

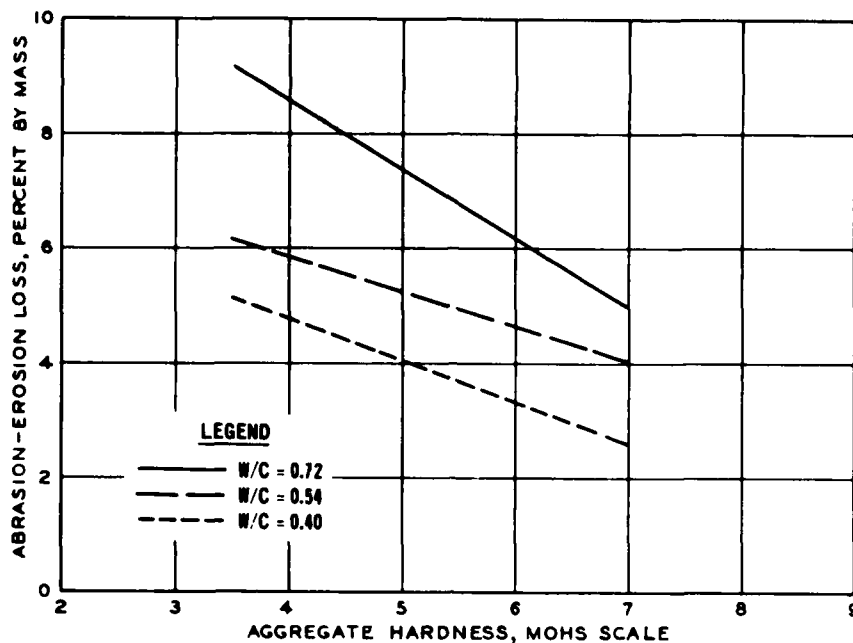


Figure 31. Relationship between aggregate hardness and abrasion-erosion loss of concrete

the hardness of the aggregate.\* Concrete containing soft aggregate was less resistant to abrasion-erosion than similar concretes containing relatively harder aggregates. This same trend was also evident in fiber-reinforced concrete (Figure 32). The average 72-hr abrasion-erosion loss of fiber-reinforced concrete containing limestone (Mohs hardness = 3.5) was approximately 39 percent higher than that of fiber-reinforced concrete containing siliceous gravel (average Mohs hardness = 6.1).

#### Effects of Concrete Type

68. The relative abrasion-erosion resistance of conventional concrete, fiber-reinforced concrete, polymer-impregnated concrete, polymer

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\* Although the quartzite is slightly harder than the trap rock and chert, the abrasion-erosion loss of concrete containing quartzite was found to be higher than that of the concrete containing trap rock and chert. The weathered quartzite aggregates used in this test program may have contributed the greater abrasion-erosion loss.

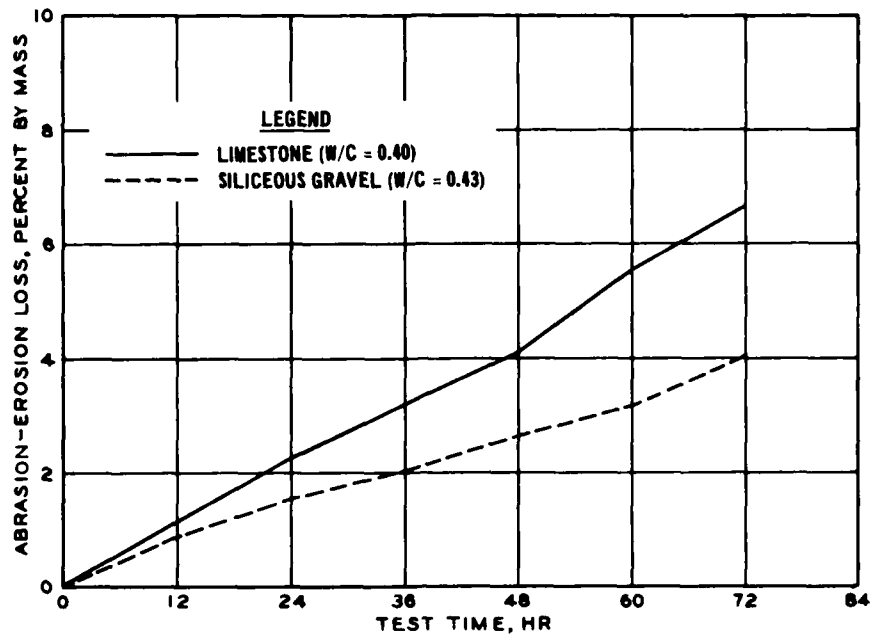


Figure 32. Effects of aggregate type on abrasion-erosion resistance of fiber-reinforced concrete

portland cement concrete, methyl methacrylate polymer concrete, and vinyl ester polymer concrete was investigated in this program. The results are evaluated and presented in the following paragraphs.

#### Fiber-reinforced concrete

69. A comparison of the results of Batches T1 and F4 (Figure 33), which contain limestone aggregates and have a water-cement ratio of 0.72, indicated that the fiber-reinforced concrete was less resistant to abrasion-erosion than the conventional concrete of same aggregate type and water-cement ratio. The average 72-hr abrasion-erosion loss of fiber-reinforced concrete was approximately 22 percent higher than that of the conventional concrete. Figures 34 and 35 indicated that the abrasion-erosion losses of fiber-reinforced concretes were consistently higher than those of the conventional concretes over wide ranges of water-cement ratio and compressive strength. The poor performance of the fiber-reinforced concrete subjected to abrasion-erosion may be attributed to two factors.

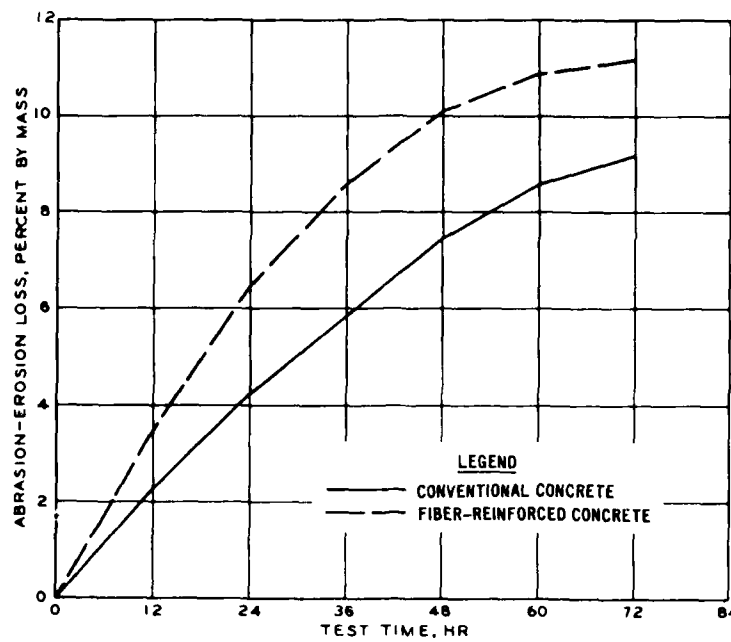


Figure 33. Effects of concrete type on abrasion-erosion resistance (W/C = 0.72, limestone aggregate)

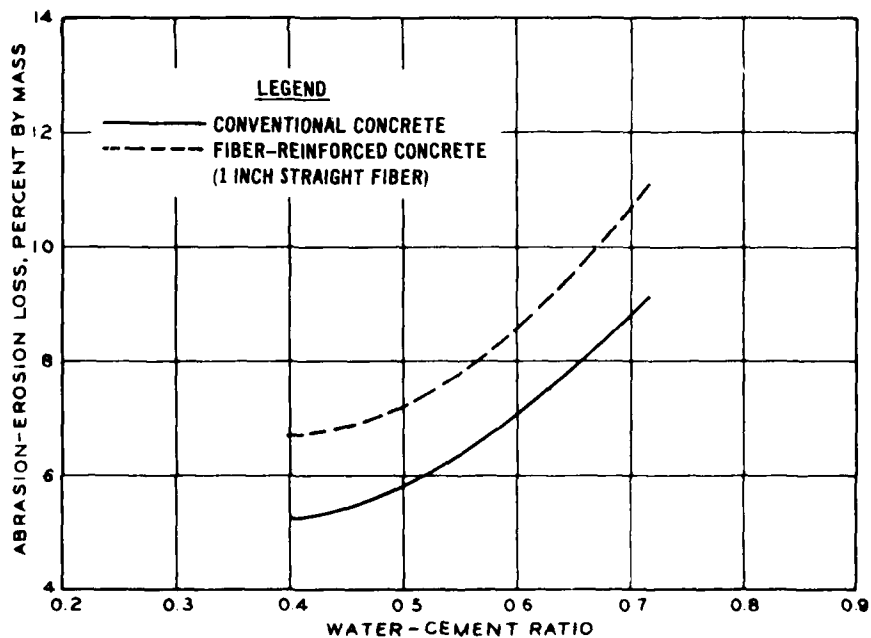


Figure 34. Relationship between water-cement ratio and abrasion-erosion resistance of conventional concrete and fiber-reinforced concrete

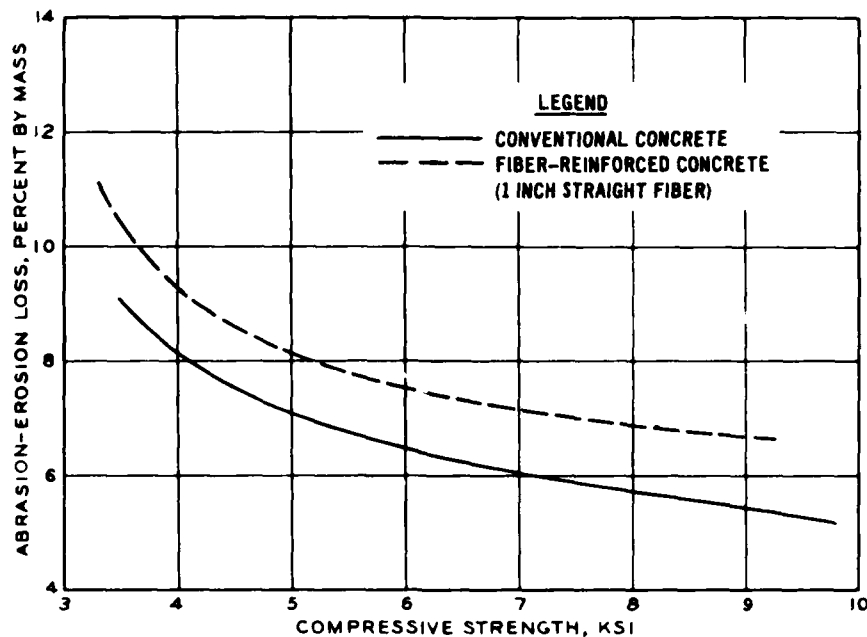


Figure 35. Relationship between compressive strength and abrasion-erosion resistance of conventional concrete and fiber-reinforced concrete

- a. The fiber-reinforced concrete generally has less coarse aggregate content per unit volume of concrete than that of the comparable conventional concrete. As discussed previously, the coarse aggregate contributes significantly to the abrasion-erosion resistance of concrete. Therefore, it is reasonable to expect that the fiber-reinforced concrete is less resistant to abrasion-erosion than the conventional concrete.
- b. When fiber-reinforced concrete is subjected to abrasion-erosion, the film of surface mortar resists the abrasion-erosion forces initially; but as the surface mortar is worn away, the fibers are exposed. The water flow and the movement of the abrasive charges in the test environment cause the exposed fibers to vibrate. As the fiber vibrates, it introduces large stresses in the concrete due to stress concentration. These large stresses contribute to further deterioration of the concrete around the fibers. The behavior was evidenced by the deteriorated concrete around the circumference of the fibers on the surface of the test specimens.

70. The effects of fiber length on the abrasion-erosion resistance of fiber-reinforced concrete can be seen from Figure 36, where

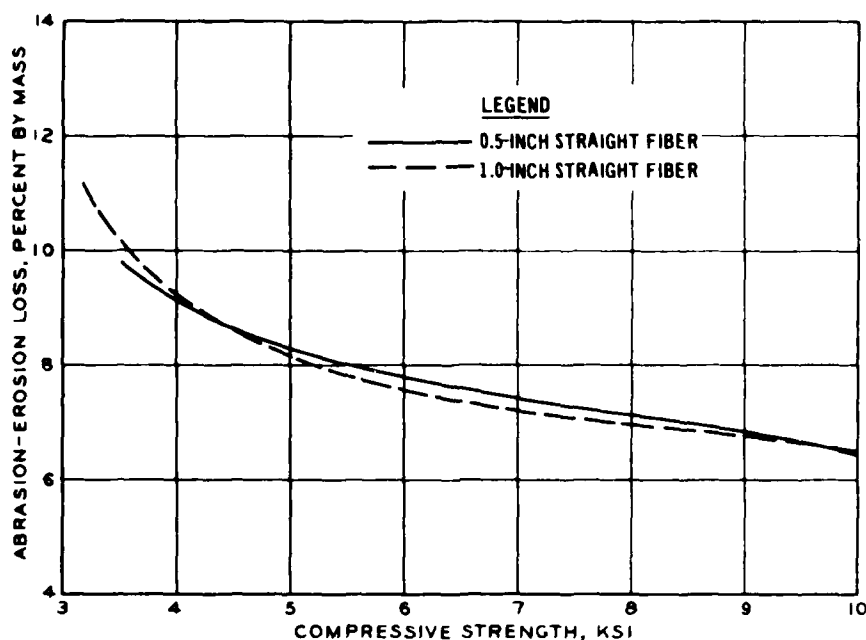


Figure 36. Effect of fiber length on the abrasion-erosion resistance of fiber-reinforced concrete

the average 72-hr abrasion-erosion losses of fiber-reinforced concretes containing 0.5-in. and 1.0-in. straight steel fibers are plotted against their compressive strengths. The lengths of the fiber being investigated apparently had very little effect on the abrasion-erosion resistance of fiber-reinforced concrete.

71. It was claimed that the collated and hooked fibers would improve workability, eliminate balling, and improve the static and dynamic properties of concrete (Bekaert Steel Wire Corporation 1975). The abrasion-erosion resistance of fiber-reinforced concretes containing two sizes of hooked fibers, 1.2- and 2-in. lengths, was investigated. A comparison of the results of Batches F2, F5, F7, and F8, which contain limestone aggregates and have a water-cement ratio of 0.54, indicated that the abrasion-erosion loss of the fiber-reinforced concrete containing hooked fibers was approximately 16 percent less than that of the comparable fiber-reinforced concrete containing straight fibers (Figure 37). The improvement in abrasion-erosion resistance of concrete

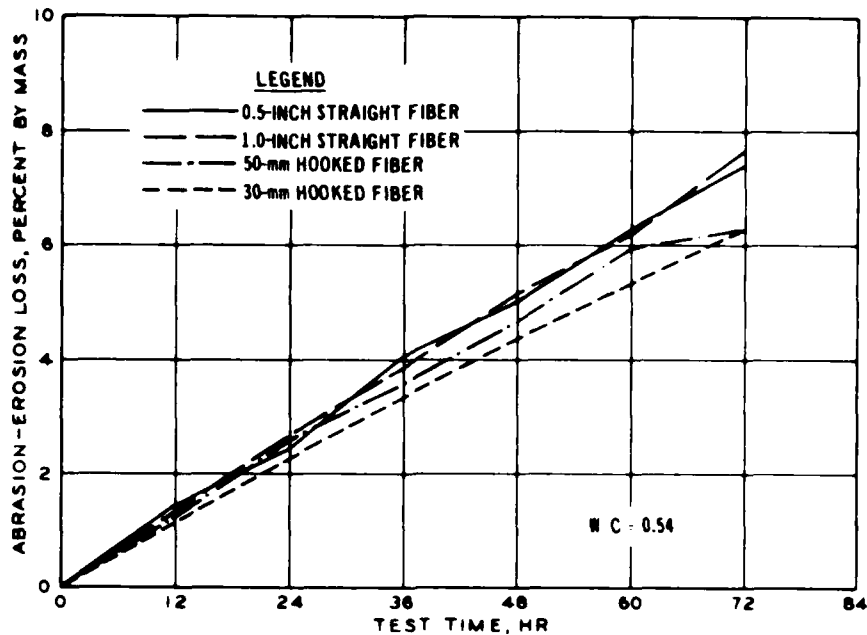


Figure 37. Abrasion-erosion resistance of fiber-reinforced concretes containing straight fibers and hooked fibers

containing hooked fibers was probably due to the fact that there were fewer fibers in the concrete containing hooked fibers (e.g., 90 lb/cu yd of hooked fibers were used in Batches F7 and F8 and about 127.5 lb/cu yd of straight fibers were caused in Batches F2 and F5) and therefore fewer stress raisers in the concrete containing hooked fibers.

#### Polymer-impregnated concrete

72. Figure 38 plots the abrasion-erosion resistance against test time for conventional concrete (Batch T1) and polymer-impregnated concrete (Batch M1), which contain limestone aggregates and have a water-cement ratio of 0.72. As expected, the abrasion-erosion resistance of polymer-impregnated concrete was significantly superior to the companion unpolymerized concrete. The average 72-hr abrasion-erosion loss was reduced approximately 70 percent by polymer impregnation.

73. Batches F9 and M3 were fabricated by the Seattle District during the repair of Libby Dam stilling basin. They each contained siliceous gravel aggregates and 1.0-in. steel fibers. The M3 specimens

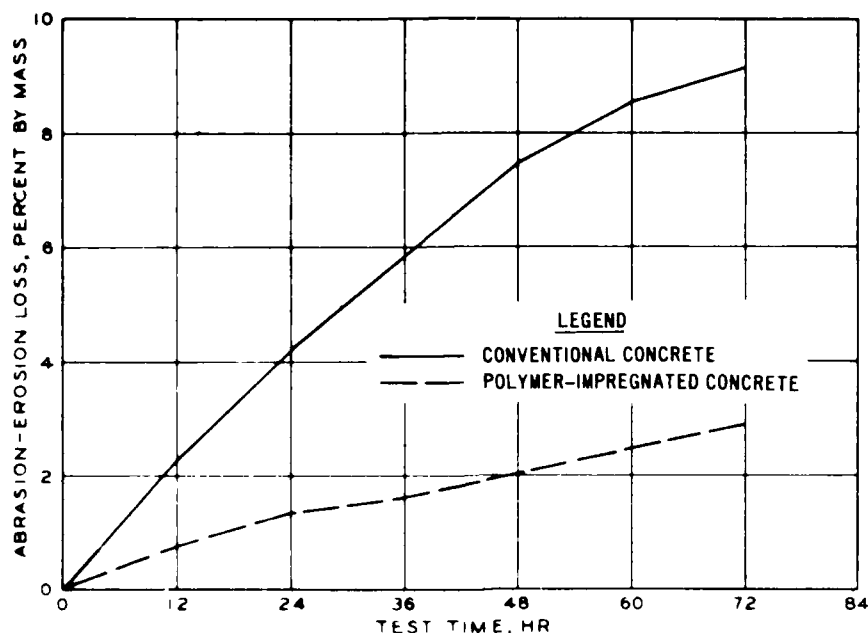


Figure 38. Abrasion-erosion resistance of conventional concrete and polymer-impregnated concrete

were polymer-impregnated fiber-reinforced concrete similar to that used in 4-ft sections along construction joints in the stilling basin. The abrasion-erosion resistance of these materials is plotted in Figure 39. The average 72-hr abrasion-erosion resistance of fiber-reinforced concrete improved by approximately 45 percent by polymer-impregnation.

#### Polymer portland cement concrete

74. Figure 40 plots the abrasion-erosion resistance of conventional concrete (Batch T2) and polymer portland cement concrete, PPCC, (Batch M2), which contain limestone aggregates and have a water-cement ratio of approximately 0.54.\* The average 72-hr abrasion-erosion loss of the polymer portland cement concrete was approximately 34 percent lower than that of the comparable conventional concrete.

\* For the PPCC, the water-cement ratio was 0.30 and that of the polymer-cement ratio was 0.2.

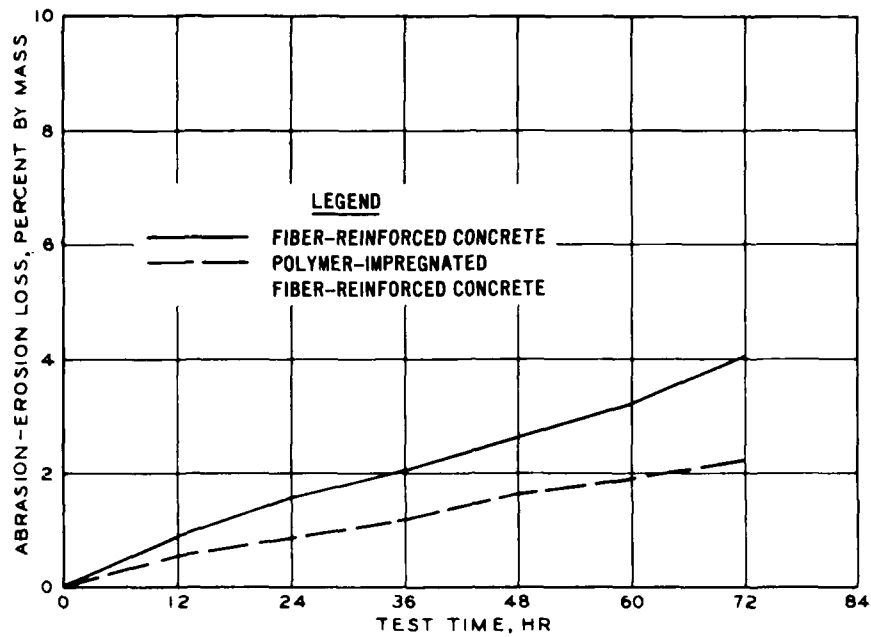


Figure 39. Abrasion-erosion resistance of fiber-reinforced concrete and polymer-impregnated fiber-reinforced concrete

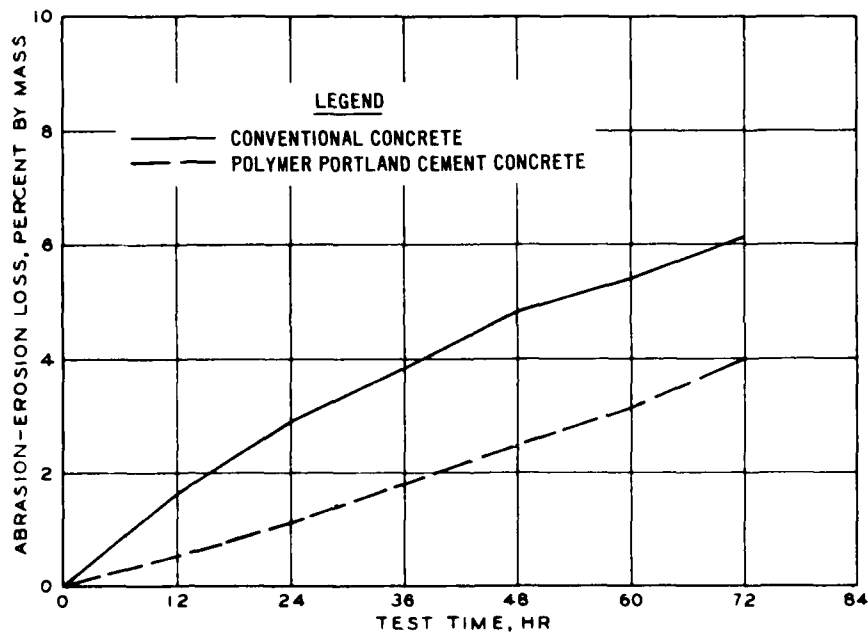


Figure 40. Abrasion-erosion resistance of conventional concrete and polymer portland cement concrete

### Polymer concretes

75. The relative abrasion-erosion resistance of four different types of polymer concretes (i.e., polymer-impregnated concrete, polymer portland cement concrete, methyl methacrylate polymer concrete, and vinyl ester polymer concrete), which all contained limestone aggregates, is shown in Figure 41. Among these polymer concretes tested,

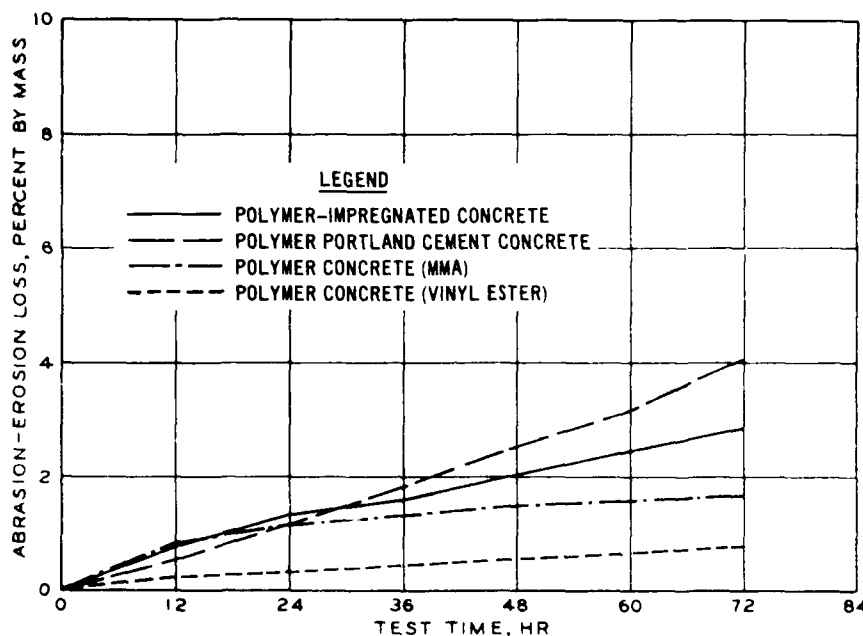


Figure 41. Abrasion-erosion resistance of polymer concretes

the vinyl ester polymer concrete ranked first in abrasion-erosion resistance, followed by methyl methacrylate polymer concrete, polymer-impregnated concrete, and polymer portland cement concrete. If the 72-hr abrasion-erosion loss for vinyl ester polymer concrete was considered unity, the abrasion-erosion losses of methyl methacrylate polymer concrete, polymer-impregnated concrete, and polymer portland cement concrete were 2.14, 2.82, and 5.18, respectively.

### Concrete containing fly ash

76. Concrete mixture proportions for Batches T2 and T26 were essentially identical except that 25 percent (by volume) of the

portland cement in Batch T2 was replaced by fly ash in Batch T26. Since the development of strength in concrete containing fly ash is slower than that of the concrete containing portland cement alone, the Batch T26 specimens were tested at the age of 94 days whereas the T2 specimens were tested at 28 days. The average compressive strengths at the time of abrasion-erosion tests were 6870 psi and 7170 psi for Batches T2 and T26, respectively. A comparison of the abrasion-erosion test results indicated that the concrete containing fly ash had less abrasion-erosion loss during the first 36 hr than the concrete without fly ash. However, the trend was reversed after 36 hr, and the total abrasion-erosion loss of concrete containing fly ash at 72 hr was approximately 24 percent higher than that of the concrete without fly ash (Figure 42).

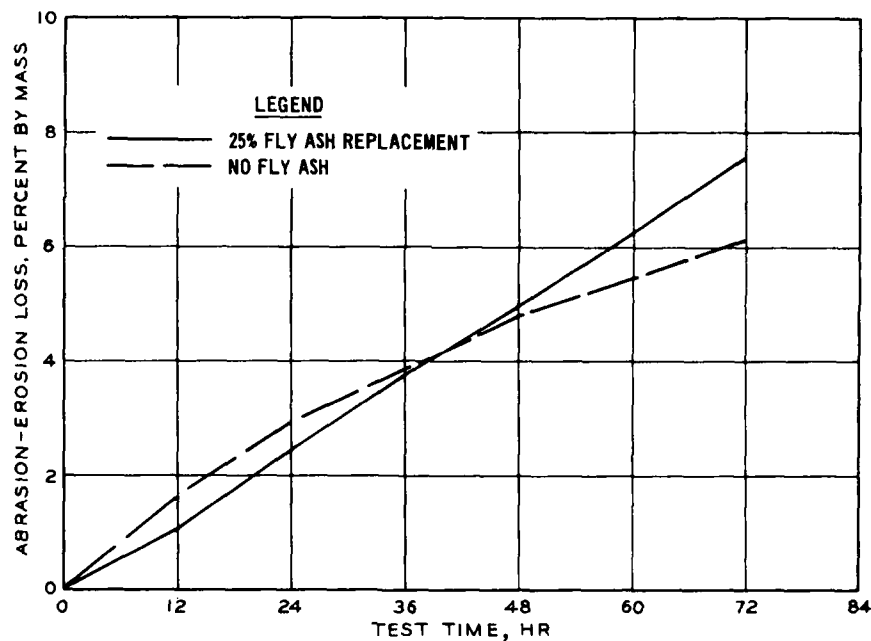


Figure 42. Abrasion-erosion resistance of concretes with and without fly ash

#### Effects of Surface Treatment

##### Vacuum treatment

77. The vacuum treatment in which excess water is extracted from

a concrete mixture by applying suction has been used for a number of years in various parts of the world (U. S. Bureau of Reclamation 1943; Lewis, Mattison, and Smith 1973; Boija, Larsson, and Sandburg 1972; and Garnett 1959). In this test program, the effect of vacuum treatment on the abrasion-erosion resistance of concretes with water-cement ratios of 0.72 and 0.54 (Batches T17 and T27, respectively) was investigated. The test results, which are plotted in Figures 43 and 44, indicated that the abrasion-erosion resistance was significantly higher for vacuum-treated concrete than for nonprocessed concrete. The average 72-hr abrasion-erosion losses were reduced 44 percent and 39 percent by vacuum treatment for concretes with water-cement ratios of 0.72 and 0.54, respectively. The improvement in abrasion-erosion resistance of vacuum-treated concrete was due principally to the reduction of the water content in the concrete mixture.

#### Surface coatings

78. The relative abrasion-erosion resistance of seven different

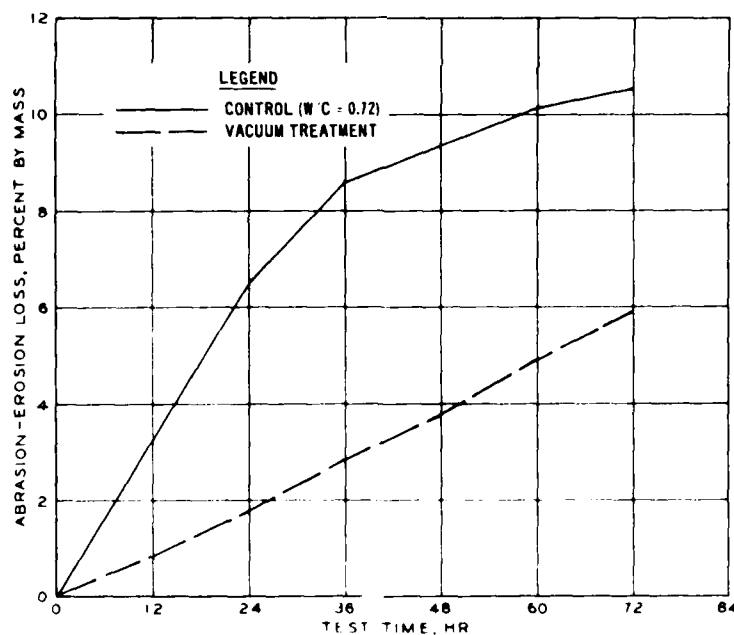


Figure 43. Effects of vacuum treatment on abrasion-erosion resistance of concrete with W/C = 0.72

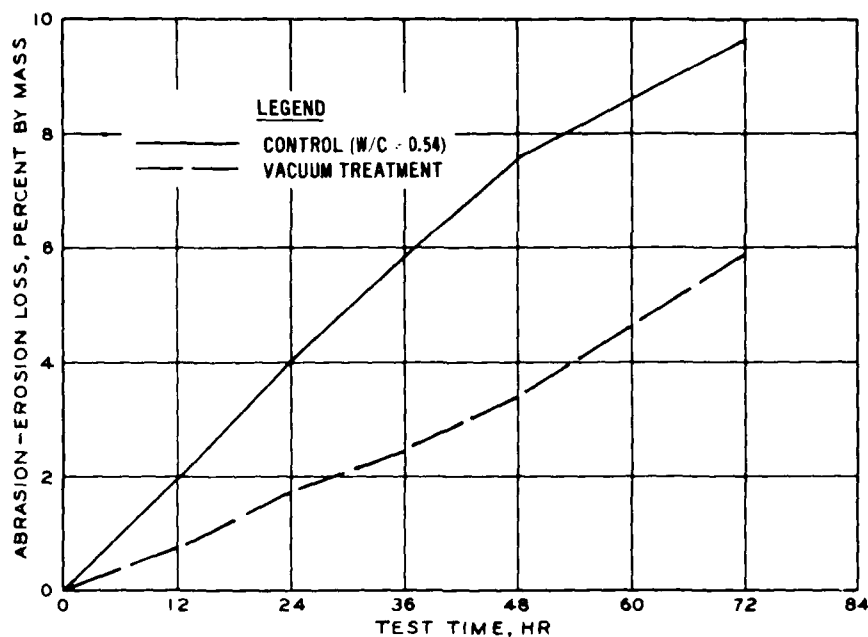


Figure 44. Effect of vacuum treatment on abrasion-erosion resistance of concrete with W/C = 0.54

types of concrete surface coatings (i.e., two types of polyurethane coating, acrylic mortar, high modulus and low modulus epoxy resin mortar, furan resin, and iron aggregate topping) was investigated. In general, all surface coatings investigated had good resistance to abrasion-erosion. The abrasion-erosion losses of all coatings were significantly less than the conventional concrete. The test results are shown in Figure 45.

79. Both polyurethane coatings (Batches T19 and T21) exhibited excellent abrasion-erosion resistance with essentially no loss in 72 hr. The resilience of the polyurethane coatings may have cushioned the impact of the abrasion charges, and therefore resulted in this excellent performance.

80. The two epoxy resin mortar coatings (Batches T22 and T23) tested had essentially the same abrasion-erosion loss at 72 hr. The average abrasion-erosion losses at 72 hr were 0.23 percent and 0.24

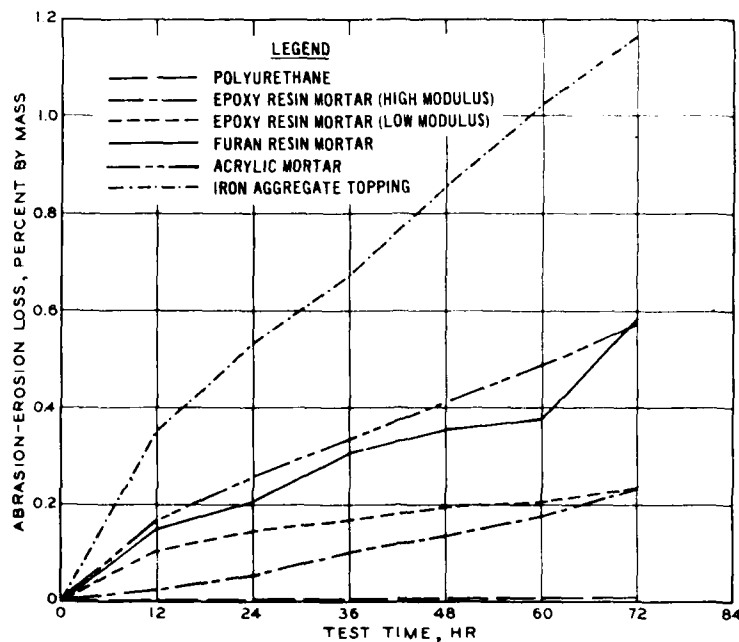


Figure 45. Abrasion-erosion resistance of various concrete surface coatings

percent for low modulus and high modulus epoxy resin mortar coatings, respectively.

81. The furan resin mortar and acrylic mortar had approximately the same abrasion-erosion loss at 72 hr. The average abrasion-erosion losses at 72 hr were 0.58 percent and 0.57 percent for furan resin mortar and acrylic mortar, respectively. During the test, it was noticed that the furan resin mortar did not bond well to the base concrete.\* The interface cracks were developed after 24 hr of testing, and the coating of one of the specimens was completely separated from the base concrete in 60 hr.

82. Among the surface coatings investigated, the iron aggregate topping had the largest amount of abrasion-erosion loss. The average 72-hr abrasion-erosion loss of the iron aggregate topping was 1.16 percent.

\* A small amount of epoxy resin may be added to the furan resins to increase the bond.

## PART V: CONCLUSIONS AND RECOMMENDATIONS

83. This report presents the results of tests conducted to evaluate the relative abrasion-erosion resistance of various materials considered for use in repair of concrete stilling basins. General conclusions and recommendations based on the test data obtained are formulated and discussed in the following paragraphs.

### Conclusions

84. The abrasion-erosion test method developed in this test program is suitable for evaluating the relative resistance of concrete surfaces subjected to abrasive action of waterborne particles. Meaningful evaluation of abrasion-erosion resistance of concrete to such action has not been possible heretofore.

85. The abrasion-erosion resistance of concrete for a given aggregate increased with decrease in water-cement ratio. A reduction in water-cement ratio from 0.72 to 0.40 resulted in approximately 43 percent, 48 percent, 56 percent, and 30 percent improvements in abrasion-erosion resistance for concrete containing limestone, chert, trap rock, and quartzite, respectively.

86. For the same aggregate, the abrasion-erosion resistance of concrete increased with an increase in compressive strength. The average abrasion-erosion resistance of concrete increased approximately 44 percent as the compressive strength increased from 3000 psi to 9000 psi.

87. Test results indicated that the type of aggregates has a significant effect on the abrasion-erosion resistance of concrete that contains them. The abrasion-erosion loss of concrete containing limestone aggregate was approximately twice as much as that of the concrete containing chert.

88. No relationship existed between the abrasion-erosion resistance of concrete and the resistance of aggregate to abrasion as determined by the Los Angeles abrasion tests. However, highly significant correlation existed between the abrasion-erosion resistance and the

hardness of the aggregate. Concrete containing soft aggregate was less resistant to abrasion-erosion than were similar concretes containing relatively harder aggregates.

89. The fiber-reinforced concrete was less resistant to abrasion-erosion than the conventional concrete of same aggregate type and water-cement ratio. The average 72-hr abrasion-erosion loss of fiber-reinforced concrete was approximately 22 percent higher than that of the conventional concrete; both concretes contain limestone aggregates and have a water-cement ratio of 0.72.

90. The abrasion-erosion resistance of polymer-impregnated concrete was significantly superior to the companion unpolymerized concrete. The average 72-hr abrasion-erosion losses reduced approximately 70 percent and 45 percent by polymer impregnation for conventional limestone concrete and siliceous gravel fiber-reinforced concrete, respectively.

91. The abrasion-erosion resistance of polymer portland cement concrete was approximately 34 percent higher than that of the comparable conventional concrete.

92. Among the polymer concretes tested, the vinyl ester polymer concrete ranked first in abrasion-erosion resistance, followed by methyl methacrylate polymer concrete, polymer-impregnated concrete, and polymer portland cement concrete. If the 72-hr abrasion-erosion loss for vinyl ester polymer concrete was considered unity, the abrasion-erosion losses of methyl methacrylate polymer concrete, polymer-impregnated concrete, and polymer portland cement concrete were 2.14, 2.82, and 5.18, respectively.

93. The total abrasion-erosion loss of concrete containing fly ash at 72 hr was approximately 24 percent higher than that of the concrete without fly ash.

94. The abrasion-erosion resistance was significantly higher for vacuum-treated concrete than it was for nonprocessed concrete. The average 72-hr abrasion-erosion losses reduced by 44 percent and 39 percent by vacuum treatment for concretes with water-cement ratios of 0.72 and 0.54, respectively.

95. All surface coatings investigated had good resistance to abrasion-erosion. The polyurethane coatings had essentially no abrasion-erosion loss in 72 hr. The average abrasion-erosion losses at 72 hr were 0.23 percent, 0.24 percent, 0.58 percent, 0.57 percent, and 1.16 percent for low modulus epoxy resin mortar, high modulus epoxy resin mortar, furan resin mortar, acrylic mortar, and iron aggregate topping, respectively.

#### Recommendations

96. The abrasion-erosion test method, presented in Appendix C, is recommended for inclusion in the "Handbook for Concrete and Cement" (WES 1949) as a standard test method for determining the relative resistance of concrete surfaces to abrasion-erosion under water.

97. Fiber-reinforced concrete should not be used for new construction or repair of stilling basins or other hydraulic structures where abrasion-erosion is of major concern.

98. Pending further studies of laboratory and field performance tests on polymer concretes and concrete coatings, conventional concrete of the lowest practical water-cement ratio and of the hardest available aggregates is recommended for use in new construction and for repair to existing hydraulic structures where abrasion-erosion is to be expected.

99. The abrasion-erosion resistance of polymer concrete is significantly superior to the conventional concrete. The technical and economic feasibility of using both cast-in-place and precast polymer concrete elements for stilling basins and other hydraulic structures should be investigated.

100. The principal disadvantages of polyurethane coatings relate to the necessity for very careful surface preparation before application. The toughness of the coatings is so great that unless precautions are taken to obtain the highest adhesion, the coating can strip away from the substrate in large sheets (American Concrete Institute 1978). In a very limited field test, the material had blisters and some areas of bond failure after 2 years exposure under water (McDonald, 1980). The

long-term dimensional stability and adhesion and tear properties of these coatings under field conditions should be investigated. Other surface coatings investigated in this test program are also promising. Field tests of these coatings at selected stilling basins are recommended.

101. The vacuum treatment significantly improves the abrasion-erosion resistance of conventional concrete. This method appears to be suitable for use in the stilling basin floor construction, and a field investigation is recommended.

102. The limited tests indicated that the abrasion-erosion loss of concrete containing fly ash was higher than that of the concrete without fly ash. However, this result may not be conclusive because insufficient tests were made. Since most of the concrete for the hydraulic structures contain fly ash, it is recommended that additional laboratory tests be conducted.

103. A recent survey indicated that most of the severe abrasion-erosion damage in the stilling basin is located at or near the construction or contraction joints (McDonald, 1980). The abrasion-erosion resistance of various types of joints should be studied. Furthermore, the effects of placing, finishing, and curing of concrete on the abrasion-erosion resistance of concrete should also be studied.

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Table 1  
Concrete Abrasion-Erosion Test Program and Results

Batch	Concrete Type*	Aggregate Type	Fiber Type	Comp. Str psi	Flex. Str psi	Surface Treatment	Avg Abrasion Loss at 72-hr %	Fresh Concrete Properties			Remarks
								W/C	Slump in.	Air %	
T1	CC	Limestone	--	3,470	675	None	9.12	0.72	1-1/2	6.0	
T2	CC	Limestone	--	6,870	920	None	6.12	0.54	6	1.1	
T3	CC	Limestone	--	9,820	1085	None	5.18	0.40	4-1/4	5.2	
T4	CC	Chert	--	3,330	503	None	4.79	0.72	3	5.3	
T5	CC	Chert	--	6,590	734	None	3.81	0.54	3-1/2	1.5	
T6	CC	Chert	--	9,020	910	None	2.47	0.40	1/2	2.5	
T7	CC	Trap Rock	--	3,300	597	None	5.73	0.72	1/2	6.5	
T8	CC	Trap Rock	--	6,370	840	None	4.42	0.54	1-3/4	2.5	
T9	CC	Trap Rock	--	9,970	1050	None	2.51	0.40	2	1.5	
T10	CC	Quartzite	--	3,400	480	None	6.33	0.72	1-1/2	5.4	
T11	CC	Quartzite	--	6,470	750	None	4.86	0.54	2	2.4	
T12	CC	Quartzite	--	9,050	915	None	4.41	0.40	1-1/2	2.2	
T13	CC	Granite	--	3,630	--	None	6.84	0.50	2-1/4	4.7	
T14	CC	Granite	--	3,260	--	None	6.92	0.55	4	4.6	
T15	CC	Slag	--	4,640	--	None	8.35	0.50	2	5.5	Fontana Slag
T16	CC	Slag	--	3,310	--	None	8.13	0.55	3-3/4	6.0	Fontana Slag
T17	CC	Limestone	--	3,180	640	Vacuum	5.90	0.72	2.0	3.5	

(Continued)

\* CC = conventional concrete.

(Sheet 1 of 3)

Table 1 (Continued)

Batch	Concrete Type*	Aggregate Type	Fiber Type	Comp. Str psi	Flex. Str psi	Surface Treatment	Avg Abrasion Loss at 72-hr %	Fresh Concrete Properties			Remarks
								W/C	Slump in.	Air %	
T18	CC	Siliceous Gravel	--	7,570	915	None	6.35	0.43	5	4.1	Libby Concrete
T19	CC	Limestone	--	--	--	Polyurethane	NIL	0.72	1-1/2	6.0	GS-300/GS-600
T20	CC	Limestone	--	--	--	Acrylic Mortar	0.57	0.72	1-1/2	6.0	SILIKAL-R7
T21	CC	Limestone	--	--	--	Polyurethane	NIL	0.72	1-1/2	6.0	PR-1654
T22	CC	Limestone	--	--	--	Epoxy Resin Mortar	0.23	0.72	1-1/2	6.0	Low Modulus
T23	CC	Limestone	--	--	--	Epoxy Resin Mortar	0.24	0.72	1-1/2	6.0	High Modulus
T24	CC	Limestone	--	--	--	Furan Resin	0.58	0.72	1-1/2	6.0	Poor Adhesion to Concrete
T25	CC	Limestone	--	--	--	Iron Agg. Topping	1.16	0.72	1-1/2	6.0	Anvil Top
T26	CC	Limestone	--	7,170	970	None	7.59	0.54	6	0.8	25% Fly Ash Replacement
T27	CC	Limestone	--	5,420	--	Vacuum	5.90	0.54	6	1.1	
F1	FRC	Limestone	Straight (0.5 in.)	3,500	760	None	9.73	0.72	1/2	6.6	
F2	FRC	Limestone	Straight (0.5 in.)	6,920	949	None	7.39	0.54	1	1.9	

(Continued)

\* CC = conventional concrete; FRC = fiber-reinforced concrete.

(Sheet 2 of 3)

Table 1 (Concluded)

Batch	Concrete Type*	Aggregate Type	Fiber Type	Comp. Str psi	Flex. Str psi	Surface Treatment	Avg Abrasion Loss at 72-hr %	Fresh Concrete Properties			Remarks
								W/C	Slump in.	Air %	
F3	FRC	Limestone	Straight (0.5 in.)	10,500	1070	None	6.04	0.40	1	4.0	
F4	FRC	Limestone	Straight (1.0 in.)	3,150	725	None	11.17	0.72	1 1/4	6.6	
F5	FRC	Limestone	Straight (1.0 in.)	5,770	1030	None	7.66	0.54	1-1/4	1.8	
F6	FRC	Limestone	Straight (1.0 in.)	9,260	1080	None	6.64	0.40	2	5.0	
F7	FRC	Limestone	Hooked (50/0.50)	6,660	975	None	6.22	0.54	1-3/4	2.3	
F8	FRC	Limestone	Hooked (30/0.40)	7,370	970	None	6.22	0.54	3	2.1	
F9	FRC	Siliceous Gravel	Straight (1.0 in.)	6,420	--	None	4.02	0.43	2-3/8	3.0	Libby Concrete
M1	PC	Limestone	--	--	--	PIC	2.84	0.72	1-1/2	6.0	
M2	PC	Limestone	--	8,080	--	PPCC	4.04	0.3	1/2	--	P/C = 0.2
M3	PC	Siliceous Gravel	Straight (1.0 in.)	6,420	--	PIC	2.20	0.43	2-3/8	3.0	Libby Concrete
M4	PC	Limestone	--	--	--	PC (MMA)	1.67	--	--	--	
M5	PC	Limestone	--	--	--	PC (Vinyl-ester)	0.78	--	--	--	

\* FRC = fiber-reinforced concrete; PC = polymer concrete.

(Sheet 3 of 3)

Table 2

## Concrete Mixture Proportions

Batch	Coarse					Steel Fiber lb/cu yd	Unit Weight lb/cu yd	Remarks
	Water lb/cu yd	Cement lb/cu yd	Aggregate 3/4 in. to No. 4 lb/cu yd	Fine Aggregate lb/cu yd				
T1	277.2	385.0	1707.3	1502.8	--	--	143.4	
T2	354.6	656.7	1556.1	1484.0	--	--	150.1	
T3	290.1	708.0	1504.7	1435.4	--	--	145.9	
T4	277.2	385.0	1781.8	1262.4	--	--	137.3	
T5	298.0	584.0	1847.5	1255.7	--	--	147.6	
T6	286.0	880.0	1741.3	1135.2	--	--	149.7	
T7	277.0	385.0	1751.3	1530.7	--	--	146.1	
T8	355.0	657.0	1597.0	1511.0	--	--	152.6	
T9	354.6	886.5	1521.6	1384.3	--	--	153.6	
T10	277.0	385.0	1645.0	1458.0	--	--	139.4	
T11	355.0	657.0	1499.0	1440.0	--	--	147.8	
T12	354.6	886.5	1493.5	1272.1	--	--	148.4	
T13	258.5	517.0	1801.8*	1258.1	--	--	142.1	
T14	284.4	517.0	1764.4*	1230.1	--	--	140.6	
T15	258.5	517.0	1590.8*	1216.1	--	--	132.7	
T16	284.4	517.0	1555.2*	1188.9	--	--	131.3	
T17	284.4	395.3	1752.8	1542.8	--	--	147.3	

(Continued)

\* Maximum aggregate size = 1-1/2 in.

Table 2 (Concluded)

Batch	Water lb/cu yd	Cement lb/cu yd	Coarse Aggregate		Fine Aggregate lb/cu yd	Steel Fiber lb/cu yd	Unit Weight lb/cu yd	Remarks
			3/4 in. to No. 4 lb/cu yd	lb/cu yd				
T18	275.0	447.0	1451.0		1591.0	--	146.4	189 lb/cu yd of pozzolan added
T19-T25	277.2	385.0	1707.3		1502.8	--	143.4	
T26	336.0	493.0	1581.0		1508.0	--	149.9	130 lb/cu yd of pozzolan added
T27	354.6	656.7	1556.1		1484.0	--	150.1	
F1	277.0	385.0	1664.0		1503.0	121.1	146.3	
F2	355.0	656.7	1511.0		1484.0	127.5	153.1	
F3	293.0	715.0	1400.0		1450.0	120.0	147.3	
F4	277.0	385.0	1664.0		1503.0	121.1	146.3	
F5	355.0	656.7	1511.0		1484.0	127.6	153.1	
F6	295.3	720.8	1411.1		1461.6	120.3	148.5	
F7	355.0	656.7	1522.0		1484.0	95.0	152.3	
F8	355.0	656.7	1522.0		1484.0	95.0	152.3	
F9	275.0	447.0	1353.0		1591.0	141.0	150.1	189 lb/cu yd of pozzolan added
M1	277.2	385.0	1707.3		1502.8	--	143.4	
M2	197.6	658.8	1555.2		1468.8	--	--	131.8 lb of epoxy added
M3	275.0	447.0	1353.0		1591.0	141.0	150.1	189 lb/cu yd of pozzolan added

Table 3  
Abrasion-Erosion Test Data

Batch	Specimen No.	Abrasion-Erosion Loss, Percent by Mass					
		12 hr	24 hr	36 hr	48 hr	60 hr	72 hr
T1	1	2.74	4.77	6.52	8.16	8.74	9.31
T1	2	1.65	3.38	5.64	6.83	8.24	8.43
T1	3	2.41	4.46	5.30	7.27	8.63	9.63
T1	Average	2.27	4.20	5.82	7.42	8.54	9.12
T2	1	1.72	3.00	4.24	5.24	5.80	6.32
T2	2	1.68	2.86	3.83	4.72	5.23	5.87
T2	3	1.61	2.85	3.42	4.46	5.16	6.17
T2	Average	1.67	2.90	3.83	4.81	5.40	6.12
T3	1	1.23	2.21	3.24	4.01	5.29	6.40
T3	2	1.20	1.70	2.47	3.10	3.82	4.71
T3	3	0.79	1.33	1.92	2.48	3.58	4.42
T3	Average	1.07	1.75	2.54	3.20	4.23	5.18
T4	1	1.27	1.89	3.00	3.91	4.26	4.86
T4	2	1.42	1.97	2.75	3.50	4.13	4.77
T4	3	1.33	1.95	2.74	3.74	4.12	4.75
T4	Average	1.34	1.94	2.83	3.72	4.17	4.79
T5	1	1.05	1.68	2.39	2.65	3.46	3.60
T5	2	1.05	2.00	2.52	3.05	3.58	4.02
T5	3	1.00	1.83	2.46	2.96	3.51	3.80
T5	Average	1.03	1.84	2.46	2.89	3.52	3.81
T6	1	0.39	1.00	1.47	1.78	2.01	2.40
T6	2	0.39	1.07	1.67	1.96	2.09	2.56
T6	3	0.41	1.06	1.55	1.84	2.05	2.46
T6	Average	0.40	1.04	1.56	1.86	2.05	2.47
T7	1	1.72	2.80	3.59	4.33	4.99	5.84
T7	2	2.21	3.55	5.10	5.70	6.10	6.28
T7	3	1.58	2.95	3.72	4.27	4.88	5.06
T7	Average	1.84	3.10	4.14	4.77	5.32	5.73
T8	1	1.54	2.69	3.40	3.71	4.58	4.81
T8	2	1.40	2.17	2.88	3.44	3.82	4.15
T8	3	1.27	2.36	2.99	3.50	3.93	4.31
T8	Average	1.40	2.41	3.09	3.55	4.11	4.42
T9	1	0.33	0.73	1.32	1.87	2.23	3.01
T9	2	0.08	0.58	0.91	1.51	2.02	2.49
T9	3	0.28	0.66	0.78	1.23	1.54	2.04
T9	Average	0.23	0.66	1.00	1.54	1.93	2.51

(Continued)

(Sheet 1 of 5)

Table 3 (Continued)

Batch	Specimen No.	Abrasion-Erosion Loss, Percent by Mass					
		12 hr	24 hr	36 hr	48 hr	60 hr	72 hr
T10	1	2.30	3.94	4.47	4.63	5.74	6.15
T10	2	2.10	3.42	4.89	4.89	5.57	5.79
T10	3	1.60	3.74	6.61	6.61	7.03	7.06
T10	Average	2.00	3.70	5.32	5.38	6.11	6.33
T11	1	1.52	2.53	3.41	4.21	4.80	5.12
T11	2	1.80	2.61	3.49	3.95	4.41	4.76
T11	3	1.46	2.53	3.51	4.12	4.57	4.71
T11	Average	1.59	2.56	3.47	4.09	4.59	4.86
T12	1	1.53	2.37	2.69	3.35	4.01	4.22
T12	2	1.19	2.25	2.73	3.39	3.79	4.37
T12	3	1.38	2.22	2.25	3.21	3.74	4.65
T12	Average	1.37	2.28	2.56	3.32	3.85	4.41
T13	1	3.11	4.54	5.19	5.73	6.27	6.32
T13	2	3.38	5.27	6.14	6.76	6.95	7.35
T13	Average	3.25	4.91	5.67	6.25	6.61	6.84
T14	1	3.71	5.19	5.86	6.32	6.80	6.94
T14	2	4.46	5.94	6.24	6.75	6.78	6.89
T14	Average	4.09	5.57	6.05	6.54	6.79	6.92
T15	1	2.71	5.16	6.48	7.13	7.81	8.54
T15	2	1.82	3.91	5.78	6.98	7.54	8.16
T15	Average	2.27	4.54	6.13	7.06	7.68	8.35
T16	1	3.58	6.19	7.97	8.63	8.89	9.12
T16	2	2.59	4.92	5.85	6.62	7.00	7.14
T16	Average	3.09	5.56	6.91	7.63	7.95	8.13
T17	1	0.92	2.11	3.37	4.61	5.47	6.58
T17	2	0.71	1.43	2.30	2.94	4.34	5.21
T17	Average	0.82	1.77	2.84	3.78	4.91	5.90
T17	Control	3.19	6.54	8.59	9.29	10.16	10.52
T18	1	1.51	2.49	3.68	4.69	5.72	6.54
T18	2	1.59	2.97	3.59	4.59	5.84	6.37
T18	3	1.96	3.28	4.47	5.02	5.87	6.13
T18	Average	1.69	2.91	3.91	4.77	5.81	6.35
T19	1	0.05	0.16	--	--	0.21	0.21
T19	2	0.08	0.11	0.08	0.03	--	0.05
T19	3	0.13	0.13	--	--	--	--
T19	Average	0.09	0.13	--	--	--	0.13

(Continued)

(Sheet 2 of 5)

Table 3 (Continued)

Batch	Specimen No.	Abrasion-Erosion Loss, Percent by Mass					
		12 hr	24 hr	36 hr	48 hr	60 hr	72 hr
T20	1	0.19	0.33	0.41	0.52	0.62	0.73
T20	2	0.14	0.24	0.30	0.38	0.46	0.52
T20	3	0.14	0.19	0.27	0.33	0.38	0.46
T20	Average	0.16	0.25	0.33	0.41	0.49	0.57
T21	1	0	0	0	0	0	0
T21	2	0.05	0.05	0.05	0.05	0.05	0.08
T21	3	0	0	0	0	0	0
T21	Average	0.02	0.02	0.02	0.02	0.02	0.03
T22	1	0.21	0.28	0.31	0.38	0.41	0.45
T22	2	0.07	0.07	0.10	0.14	0.14	0.14
T22	3	0.03	0.06	0.06	0.06	0.06	0.09
T22	Average	0.10	0.14	0.16	0.19	0.20	0.23
T23	1	0.03	0.06	0.13	0.19	0.26	0.35
T23	2	0	0.06	0.10	0.13	0.16	0.23
T23	3	0.03	0.03	0.06	0.06	0.10	0.13
T23	Average	0.02	0.05	0.10	0.13	0.17	0.24
T24	1	0.13	0.17	0.30	0.35	0.39	--
T24	2	0.17	0.22	0.30	0.35	0.35	0.58
T24	Average	0.15	0.20	0.30	0.35	0.37	0.58
T25	1	0.39	0.56	0.69	0.87	1.03	1.18
T25	2	0.31	0.49	0.64	0.83	1.01	1.14
T25	Average	0.35	0.53	0.67	0.85	1.02	1.16
T26	1	0.96	2.23	3.17	4.20	5.60	7.12
T26	2	1.08	2.57	4.12	5.53	6.72	7.98
T26	3	1.04	2.41	4.07	4.96	6.41	7.68
T26	Average	1.03	2.40	3.79	4.90	6.24	7.59
T27	1	0.75	1.47	2.49	3.26	4.17	5.94
T27	2	0.73	1.70	2.20	2.96	4.40	5.11
T27	3	0.87	2.21	2.78	3.97	5.32	6.65
T27	Average	0.78	1.79	2.49	3.40	4.63	5.90
T27	Control	1.99	4.01	5.87	7.55	8.60	9.61
F1	1	1.87	3.68	5.14	5.68	8.07	9.94
F1	2	2.16	3.27	5.27	6.43	7.83	9.55
F1	3	2.30	3.84	4.90	6.75	8.21	9.70
F1	Average	2.11	3.60	5.10	6.29	8.04	9.73
F2	1	1.77	2.91	4.10	5.36	6.57	7.71
F2	2	1.19	1.97	3.08	4.59	5.93	7.06
F2	Average	1.48	2.44	4.03	4.98	6.25	7.39

(Continued)

(Sheet 3 of 5)

Table 3 (Continued)

Batch	Specimen No.	Abrasion-Erosion Loss, Percent by Mass					
		12 hr	24 hr	36 hr	48 hr	60 hr	72 hr
F3	1	1.75	3.02	3.60	4.11	5.05	6.19
F3	2	1.62	2.63	3.52	4.10	5.55	6.26
F3	3	1.01	2.01	3.02	3.72	4.65	5.66
F3	Average	1.46	2.55	3.38	3.98	5.08	6.04
F4	1	4.39	7.96	9.95	11.37	12.14	12.40
F4	2	3.02	5.30	7.66	9.19	10.16	10.45
F4	3	2.79	5.95	7.96	9.71	10.13	10.65
F4	Average	3.40	6.40	8.52	10.09	10.81	11.17
F5	1	0.91	1.89	3.03	3.74	4.93	6.82
F5	2	1.45	2.96	4.21	5.63	6.79	8.24
F5	3	1.82	3.24	4.23	6.03	6.73	7.92
F5	Average	1.39	2.70	3.82	5.13	6.15	7.66
F6	1	1.31	2.12	3.24	4.21	5.60	6.38
F6	2	1.31	2.49	3.53	4.58	6.41	7.28
F6	3	0.90	2.01	2.84	3.48	4.59	6.27
F6	Average	1.17	2.21	3.20	4.09	5.53	6.64
F7	1	1.35	3.00	3.90	5.17	6.31	6.70
F7	2	1.08	1.88	2.96	3.84	5.40	5.65
F7	3	1.31	2.78	3.79	4.93	5.99	6.32
F7	Average	1.25	2.55	3.55	4.65	5.90	6.22
F8	1	1.14	2.34	3.23	4.40	5.59	6.35
F8	2	1.13	2.11	3.47	4.42	5.19	6.23
F8	3	1.18	2.30	3.33	4.30	5.12	6.20
F8	Average	1.15	2.25	3.34	4.37	5.30	6.22
F9	1	0.90	1.76	2.39	2.85	3.48	4.48
F9	2	0.81	1.29	1.62	2.37	2.80	3.56
F9	Average	0.86	1.53	2.00	2.61	3.14	4.02
M1	1	0.62	1.02	1.16	1.56	2.10	2.37
M1	2	0.95	1.62	2.03	2.44	2.84	3.30
M1	Average	0.79	1.32	1.60	2.00	2.47	2.84
M2	1	0.41	1.06	1.81	2.40	2.84	3.70
M2	2	0.41	1.00	1.65	2.42	2.99	4.02
M2	3	0.73	1.38	2.00	2.67	3.56	4.41
M2	Average	0.52	1.15	1.82	2.50	3.13	4.04
M3	1	0.49	0.82	1.18	1.59	1.86	2.19
M3	2	0.54	0.81	1.07	1.61	1.88	2.20
M3	Average	0.52	0.82	1.13	1.60	1.87	2.20


(Continued)

(Sheet 4 of 5)

Table 3 (Concluded)

Batch	Specimen No.	Abrasion-Erosion Loss, Percent by Mass					
		12 hr	24 hr	36 hr	48 hr	60 hr	72 hr
M4	1	1.37	1.69	1.87	2.04	2.19	2.30
M4	2	0.50	0.85	1.02	1.20	1.31	1.43
M4	3	0.61	0.82	0.96	1.08	1.17	1.28
M4	Average	0.83	1.12	1.28	1.44	1.56	1.67
M5	1	0.18	0.27	0.36	0.52	0.64	0.76
M5	2	0.27	0.39	0.49	0.58	0.67	0.82
M5	3	0.21	0.33	0.43	0.55	0.67	0.76
M5	Average	0.22	0.33	0.43	0.55	0.66	0.78

APPENDIX A  
MATERIALS AND TEST DATA

TO Mr. Tony Liu Structures Branch Structures Laboratory WES	REPORT OF TESTS OF PORTLAND CEMENT  RC-814	FROM: CORPS OF ENGINEERS U. S. ARMY Structures Laboratory USAE Waterways Exp. Sta. P. O. Box 631 Vicksburg, MS 39180
TEST REPORT NO. WES-207-78    BINDER    CAT REPRESENTED 1 Sample    DATE 21 Jun 78		
SPECIFICATION: SS-C-1960/3, Type I    DATE SAMPLED 13 Jun 78		
COMPANY: MARQUETTE    LOCATION: Brandon, MS    BRAND		
THIS CEMENT DOES <input checked="" type="checkbox"/> MEET SPECIFICATION REQUIREMENTS		
SAMPLE NO.	RC-814	
SiO <sub>2</sub> , %	19.9	
Al <sub>2</sub> O <sub>3</sub> , %	5.4	
Fe <sub>2</sub> O <sub>3</sub> , %	4.3	
H <sub>2</sub> O, %	1.7	
SO <sub>3</sub> , %	2.7	
LOSS ON IGNITION, %	1.6	
ALKALIES-TOTAL AS Na <sub>2</sub> O, %	0.27	
Na <sub>2</sub> O, %	0.11	
K <sub>2</sub> O, %	0.25	
INSOLUBLE RESIDUE, %	0.05	
ClO, %	63.8	
C <sub>3</sub> S, %	58	
C <sub>2</sub> A, %	7	
C <sub>3</sub> S, %	13	
C <sub>3</sub> A + C <sub>3</sub> S, %	65	
C <sub>4</sub> AF, %	13	
C <sub>4</sub> AF + 2 C <sub>3</sub> A, %	27.2	
HEAT OF HYDRATION, 7D, CAL/G		
HEAT OF HYDRATION, 28D, CAL/G		
SURFACE AREA, SQ CM/G (A.P.)	4040	
AIR CONTENT, %	9.2	
COMP. STRENGTH, 3 D, PSI	3450	
COMP. STRENGTH, 7 D, PSI	4570	
COMP. STRENGTH, D, PSI		
FALSE SET-PEN. P/I, %		
SAMPLE NO.	1	
AUTOClave EXP., %	-0.02	
INITIAL SET, HR/MIN	2:30	
FINAL SET, HR/MIN	5:15	
SAMPLE NO.		
AUTOClave EXP., %		
INITIAL SET, HR/MIN		
FINAL SET, HR/MIN		
REMARKS: CF: 2 cps to Tony Liu, SL, WES		
THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT		
 W.G. MILLER Chemist Chief, Cement & Pozzolan Test Branch		



5011 冊

STATE	INDEX NO.	<b>AGGREGATE DATA SHEET</b>	TESTED BY <u>KL</u>
LAT	LONG		DATE <u>1-26-79</u>
LAB SYMBOL NO.		TYPE OF MATERIAL	
LOCATION			
PRODUCER <u>Iron Mt. Trap Rock Co.</u>			
<u>Iron Mt., MO</u>			
SAMPLED BY			
TESTED FOR			
USED AS			
DRY WEIGHT BEFORE TEST NO.			
WET WEIGHT AFTER TEST NO.			
TEST RESULTS			
SIEVE		TEST RESULTS	
1/2"	100	2.79	
3/8"	77	0.3	
3/16"	46	2	
1/8"	13	2	
NO. 10	8	13.3	
NO. 20		173.8	
NO. 40			
NO. 60			
NO. 80			
NO. 100			
NO. 120			
NO. 140			
NO. 160			
NO. 180			
NO. 200			
NO. 220			
NO. 240			
NO. 260			
NO. 280			
NO. 300			
NO. 320			
NO. 340			
NO. 360			
NO. 380			
NO. 400			
NO. 420			
NO. 440			
NO. 460			
NO. 480			
NO. 500			
NO. 520			
NO. 540			
NO. 560			
NO. 580			
NO. 600			
NO. 620			
NO. 640			
NO. 660			
NO. 680			
NO. 700			
NO. 720			
NO. 740			
NO. 760			
NO. 780			
NO. 800			
NO. 820			
NO. 840			
NO. 860			
NO. 880			
NO. 900			
NO. 920			
NO. 940			
NO. 960			
NO. 980			
NO. 1000			
REMARKS			

PRO FORM 5011 R  
1 MAR 1968

PLATE A4



COFFS OF ENGINEERS U.S. ARMY  
SOUTH PACIFIC DIVISION LABORATORY  
SAN FRANCISCO, CALIFORNIA

REPORT OF PHYSICAL TESTS OF CONCRETE AGGREGATE

PROJECT Cucamonga Creek Channel				DATE September 17, 1944			
DISTRICT Los Angeles				CONTRACT NO.			
SPECIFICATION							
SAND SOURCE Fontana Slag-Filter Sand				DATE RECEIVED			
COARSE AGGREGATE SOURCE Fontana Slag				LABORATORY NO.			

SIEVE ANALYSES, CUMULATIVE % PASSING							
Base Course							
SIEVE SIZE	NO. 4	3/4"	NO. 4	3/4"	1 1/2"	2"	COARSE AGGREGATE COMBINED IN NO. 2
2 1/2"							
2"							
1 1/2"							
1"	100						
3/4"	100		100				
1/2"	81		70				
3/8"	70		10				
NO. 4	66		1				
NO. 8							

SAND				SAND			
SIEVE SIZE	NO. 4	1"	1" - 2"	SIEVE SIZE	NO. 4	1"	1" - 2"
2 1/2"				3/8"	100		
2"				NO. 4	68		
1 1/2"				NO. 8	81		
1"				NO. 16	63		
1/2"				NO. 30	48		
NO. 4				NO. 50	35		
NO. 8				NO. 100	24		

MORTAR STRENGTH				SPECIFIC GRAVITY AND ABSORPTION			
RATIO OF SAMPLE TO OTTAWA SAND		7 DAYS 28 DAYS		SIZE	BULK SP. GR.	% ABSORPTION	
				SAND	2.57	2.4	
				NO. 4 - 3/4"	2.52	4.0	
				3/4" - 1 1/2"			
				1 1/2" - 2"			
				NO. 4 - 1" 3/4" Drain	2.32	4.6	
				1" - 2"			
DECANTATION				TEST METHOD: CRD-C107 CRD-C108			
% PASSING NO. 200 SIEVE		14.2		LOS ANGELES ABRASION TEST			
TEST METHOD: CRD-C105				CLASS C and A			
				NO. REVOLUTIONS 100 500			
				WT. LOSS IN PERCENT Base 31			
				Drain 31			
				TEST METHOD: CRD-C 117			
ORGANIC IMPURITIES							
(COLORIMETRIC TEST)		Clear					
TEST METHOD: CRD-C121							

SPD Form

CORPS OF ENGINEERS, U.S. ARMY  
SOUTH PACIFIC DIVISION LABORATORY  
SAUSALITO, CALIFORNIA

REPORT OF PHYSICAL TESTS OF CONCRETE AGGREGATE

PROJECT Cucamonga Creek Channel	DATE 22 Aug 1977
DISTRICT Los Angeles	CONTRACT NO.
SPECIFICATION DATUM 9-7-B-0025	
SAND SOURCE Redlands	DATE RECEIVED 15 Aug 77
COARSE AGGREGATE SOURCE Pacific Rock	LABORATORY NO.

SIEVE ANALYSES, CUMULATIVE % PASSING

SIEVE SIZE	NO. 4 - 3/4"		3/4" - 1-1/2"		1-1/2" - 2"		COARSE AGGREGATE COMBINED IN MIX
	GRADING	SPECIFIED	GRADING	SPECIFIED	GRADING	SPECIFIED	
2-1/2"							
2"				100			
1-1/2"			100	90-100			100
1"	100	100	44	20-45			75
3/4"	97	90-100	3	0-10			55
1/2"	52		1				33
3/8"	21	20-45	0	0-5			17
NO. 4	4	0-5	0				2
NO. 8							

SIEVE SIZE	NO. 4 - 1"		1" - 2"		SIEVE SIZE	SAND	
	GRADING	SPECIFIED	GRADING	SPECIFIED		GRADING	SPECIFIED
2-1/2"					3/8"	100	100
2"					NO. 4	99	95-100
1-1/2"					NO. 8	94	80-90
1"					NO. 16	78	55-75
1/2"					NO. 30	49	30-60
NO. 4					NO. 50	25	12-30
NO. 8					NO. 100	12	2-10
					FM		

<p style="text-align: center;"><b>MORTAR STRENGTH</b></p> <p>RATIO OF SAMPLE TO OTTAWA SAND      1 <del>28</del> DAYS    <u>1.02</u></p> <p>TEST METHOD:      CRD-C 116</p>	<p style="text-align: center;"><b>SPECIFIC GRAVITY AND ABSORPTION</b></p> <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr> <th>SIZE</th> <th>BULK SP. GR.</th> <th>% ABSORPTION</th> </tr> </thead> <tbody> <tr> <td>SAND</td> <td>2.58</td> <td>1.4</td> </tr> <tr> <td>NO. 4 - 3/4"</td> <td>2.68</td> <td>1.6</td> </tr> <tr> <td>3/4" - 1-1/2"</td> <td>2.67</td> <td>1.0</td> </tr> <tr> <td>1-1/2" - 2-1/2"</td> <td></td> <td></td> </tr> <tr> <td>NO. 4 - 1"</td> <td></td> <td></td> </tr> <tr> <td>1" - 2"</td> <td></td> <td></td> </tr> </tbody> </table> <p>TEST METHOD      CRC-C 107                      CRD-C 108</p>	SIZE	BULK SP. GR.	% ABSORPTION	SAND	2.58	1.4	NO. 4 - 3/4"	2.68	1.6	3/4" - 1-1/2"	2.67	1.0	1-1/2" - 2-1/2"			NO. 4 - 1"			1" - 2"		
SIZE	BULK SP. GR.	% ABSORPTION																				
SAND	2.58	1.4																				
NO. 4 - 3/4"	2.68	1.6																				
3/4" - 1-1/2"	2.67	1.0																				
1-1/2" - 2-1/2"																						
NO. 4 - 1"																						
1" - 2"																						
<p style="text-align: center;"><b>DECANTATION</b></p> <p>% PASSING NO. 200 SIEVE      <u>6.6</u></p> <p>TEST METHOD:      CRD-C 105</p>	<p style="text-align: center;"><b>LOS ANGELES ABRASION TEST</b></p> <p>CLASS      <u>A</u></p> <p>NO. REVOLUTIONS      100      500</p> <p>WT. LOSS IN PERCENT      _____      <u>30.9</u></p> <p>TEST METHOD:      CRD-C 117</p>																					
<p style="text-align: center;"><b>ORGANIC IMPURITIES</b></p> <p>(COLORIMETRIC TEST)      _____</p> <p>TEST METHOD:      CRD-C 121</p>																						

SPD Form

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C 31)			
PROJECT NAME		SYMBOL SERIAL NO	DATE
CONCRETE REQUIRED FOR		MIXTURE NO T-1	
MATERIALS			
PORTLAND CEMENT, SS-C-192 TYPE I ADDITIONS BRAND AND MILL Marquette		POZZOLON OR OTHER CEMENT TYPE None SOURCE	AIR-ENT ADMIXTURE TYPE Hunts AMOUNT 1.5 oz cu yd
FINE AGGREGATE		COARSE AGGREGATE	
TYPE Limestone SOURCE		TYPE Limestone SIZE 3/4 in. SOURCE	
MATERIALS	SAMPLE SERIAL NO	SIZE RANGE	COARSE AGGREGATE
PORTLAND CEMENT			
FINE AGGREGATE	CL-2 MS-1(2)	No. 4 - 200	2.70
COARSE AGGREGATE A	CL-2 G-1(3)	No. 4 - 3/4 in.	2.72
COARSE AGGREGATE B			
COARSE AGGREGATE C			
COARSE AGGREGATE D			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX BY WEIGHT	SS-D WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)
PORTLAND CEMENT	1.00	385	1.959
FINE AGGREGATE	3.90	1503	8.920
COARSE AGGREGATE (A)	4.43	1707	10.059
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
WATER	0.72	277	4.442
AIR			1.620
TOTAL		3872	27.000
W/C RATIO 0.72		S.A. % VOLUME 47	
SLUMP (IN) 1.5		THEO UNIT WT (LB) CU FT	
BLEEDING %		ACTUAL UNIT WT (LB) CU FT 143.4	
AIR CONTENT % 6.0		THEO CEMENT FACT (LB) CU YD	
AIR CONTENT %		ACTUAL CEMENT FACT (LB) CU YD 385	
1. Calculated on the basis of 2. Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9 3. In the entire batch as mixed 4. In that portion of the concrete containing aggregate smaller than the 1-1/2-in. sieve * For "other cement," pozzolan, second size of fine aggregate, as may be required REMARKS Condition of mix, workability, plasticity, blending, etc.			

SSB FORM NO 553  
REV MAR-1972

PLATE A8



REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C 3)						
PROJECT NAME	SYMBOL SERIAL NO.	DATE				
CONCRETE REQUIRED FOR		MIXTURE N T-3				
MATERIALS						
PORTLAND CEMENT, SS-C-192 TYPE I ADDITIONS BRAND AND MILL Marquette	POZZOLON OR OTHER CEMENT TYPE None SOURCE	FIN. ENT. AT MIXTURE TYPE NVR AM. ENT. Lab Stock				
FINE AGGREGATE		COARSE AGGREGATE				
TYPE Limestone SOURCE	TYPE Limestone SOURCE	SIZE 3/4 in.				
MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGREGATE	FIN. ENT. AT MIXTURE	AM. ENT.	
PORTLAND CEMENT Type I	CL-2 MS-1(2)	No. 4 - 200		2.70	0.7	
FINE AGGREGATE CL-2 G-1(3)	No. 4 - 3/4 in.		2.72	0.4		
MIXTURE DATA			SPECIMEN DATA			
MATERIALS	MIX BY WEIGHT	S. S. O. WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)	CYLINDERS		BEAM
PORTLAND CEMENT HPS-R	1.00	708.0 51.0 OZ	3.602	NO.	AGE	PS.
FINE AGGREGATE	2.03	1435.4	8.520			
COARSE AGGREGATE (A)	2.13	1504.7	8.865			
COARSE AGGREGATE (B)						
COARSE AGGREGATE (C)						
COARSE AGGREGATE (D)						
WATER	0.41	290.1	4.649			
AIR			1.364			
TOTAL		3938.2	27.000			
W. CWT	0.41	S. A. S. VOLUME 49				
SLUMP IN "	4.25	THEO. UNIT WT. LB. CU FT				
BLEEDING %		ACTUAL UNIT WT. LB. CU FT 145.9				
AIR CONTENT %	5.2	THEO. CEMENT FACT. LB. CU YD				
AIR CONTENT %		ACTUAL CEMENT FACT. LB. CU YD 708.0				
1. Calculated on the basis of 2. Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9 3. In the entire batch as mixed 4. In that portion of the concrete containing aggregate smaller than the 1-1/2 in. sieve * For "other cement," pozzolan, second size of fine aggregate, as may be required						
REMARKS Condition of mix, workability, plasticity, bleeding, etc.						

RES FORM NO 553  
REV MAR 1972

PLATE A10

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C 3)						
PROJECT NAME	SYMBOL SERIAL NO					
CONCRETE REQUIRED FOR	MIXTURE NO T-4					
MATERIALS						
PORTLAND CEMENT 55-C-192 TYPE I ADDITIONS BRAND AND MILL Marquette	POZZOLON OR OTHER CEMENT TYPE SOURCE AIR-ENT ADMIXTURE TYPE Hunts AMOUNT 4.0 fl oz/cu yd					
FINE AGGREGATE	COARSE AGGREGATE					
TYPE Chert SOURCE Arkadelphia Sand & Gravel Co.	TYPE Chert SIZE 3/4 in. SOURCE Runyan Pitt					
MATERIALS	SAMPLE SERIAL NO	SIZE RANGE	COARSE ADJUST	FIN. AGG. OR FILL	ABS. WT.	
PORTLAND CEMENT						
FINE AGGREGATE	CL-20 S-1	No. 4 - 200			2.60	
COARSE AGGREGATE A	CL-22 C-1	No. 4 - 3/4 in.			2.55	
COARSE AGGREGATE B						
COARSE AGGREGATE C						
COARSE AGGREGATE D						
MIXTURE DATA			SPECIMEN DATA			
MATERIALS	MIX. BY WEIGHT	S. S. D. WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)	CYLINDERS		BEAMS
PORTLAND CEMENT	100	385.0	1.959	SIZE	NO	NO
FINE AGGREGATE	3.28	1262.4	7.781	NO	AGE	PSI
COARSE AGGREGATE A	4.63	1781.8	11.198	NO	AGE	PSI
COARSE AGGREGATE B				NO	AGE	PSI
COARSE AGGREGATE C				NO	AGE	PSI
COARSE AGGREGATE D				NO	AGE	PSI
WATER	0.72	277.2	4.442	NO	AGE	PSI
AIR			1.620	NO	AGE	PSI
TOTAL		3706.4	27.000	NO	AGE	PSI
W. C. R. 0.72			S. A. S. VOLUME 41			
SLUMP IN 4 3			THEO. UNIT WT. LB/CU FT			
BLEEDING %			ACTUAL UNIT WT. LB/CU FT 137.3			
AIR CONTENT % 5.3			THEO. CEMENT FACT. LB/CU YD			
AIR CONTENT %			ACTUAL CEMENT FACT. LB/CU YD 385.0			
1. Calculated on the basis of 2. Expressed as the percentage of mixing water separating from the concrete when tested by ASTM C 190 3. In the entire batch as mixed 4. In that portion of the concrete containing aggregate smaller than the 1.18 mm. sieve * For "other cement," pozzolan, second size of fine aggregate, as may be required						
REMARKS: Condition of mix, workability, plasticity, bleeding, etc.						

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS <small>(RD-63)</small>			
PROJECT NAME		SYMBOL SERIAL NO	DATE
CONCRETE REQUIRED FOR		MIXTURE NO <div style="text-align: right;">T-5</div>	
MATERIALS			
PORTLAND CEMENT, SS-C-192 TYPE <b>I</b> ADDITIONS BRAND AND MILL <b>Marquette</b>		POZZOLON OR OTHER CEMENT TYPE SOURCE AIR-ENT. ADMIXTURE TYPE <b>None</b> AMOUNT	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE <b>Chert</b> SOURCE <b>Arkadelphia Sand &amp; Gravel Co.</b>		TYPE <b>Chert</b> SIZE <b>3/4 in.</b> SOURCE <b>Runyan Pitt</b>	
MATERIALS	SAMPLE SERIAL NO	SIZE RANGE	COARSE AGGR. * BULK SF OR YD ABSURD
PORTLAND CEMENT			
FINE AGGREGATE	CL-20 S-1	No. 4 - 200	2.60
COARSE AGGREGATE A	CL-22 G-1	No. 4 - 3/4 in.	2.55
COARSE AGGREGATE B			
COARSE AGGREGATE C			
COARSE AGGREGATE D			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX BY WEIGHT	S & S D WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)
PORTLAND CEMENT	1.00	584.0	2.971
FINE AGGREGATE	2.15	1255.7	7.740
COARSE AGGREGATE A	3.16	1847.5	11.611
COARSE AGGREGATE B			
COARSE AGGREGATE C			
WATER	0.51	298.0	4.778
AIR			
TOTAL		3985.2	27.000
W. T. WT	0.51	S & S VOLUME 0.40	
SLUMP IN "	3.5	THEO UNIT WT. LB. CU YD	
BLEEDING %		ACTUAL UNIT WT. LB. CU YD 147.6	
AIR CONTENT %	1.5	THEO CEMENT FACT. LB. CU YD	
AIR CONTENT %		ACTUAL CEMENT FACT. LB. CU YD 584	
<small>1. Calculated on the basis of  2. Expressed as the percentage of mixing water separating from the concrete when tested by C.R.D. 1.4  3. In the entire batch as mixed  4. In that portion of the concrete containing aggregate smaller than the 1 1/2 in. sieve  * For "other cement" pozzolan, second size of fine aggregate, as may be required</small>			
REMARKS: Condition of mix, workability, plasticity, bleeding, etc.			

DES FORM NO 553  
REV MAR 1972

PLATE A12

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS FORM 3			
PROJECT NAME		SERIAL NO.	DATE
CONCRETE REQUIRED (cu yd)		MIXTURE NO. T-6	
MATERIALS			
PORTLAND CEMENT, SPEC. 192 TYPE I ADDITIONS BRAND AND MILL Marquette		AGGREGATE MIXTURE TYPE None AMOUNT	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE Chert		TYPE Chert SIZE 3/4 in.	
SOURCE Arkadelphia Sand & Gravel Co.		SOURCE Runyan Pitt	
MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	WEIGHT (lb)
PORTLAND CEMENT			
FINE AGGREGATE	CL-20 S-1	No. 4 - 200	2.60
AGGREGATE A	CL-22 G-1	No. 4 - 3/4 in.	2.55
AGGREGATE B			
AGGREGATE C			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX BY WEIGHT	WEIGHT (lb)	WEIGHT (lb)
PORTLAND CEMENT	100	880.0	4.477
FINE AGGREGATE	1.29	1135.2	6.997
AGGREGATE A	1.98	1741.3	10.943
AGGREGATE B			
AGGREGATE C			
WATER	0.325	286.0	4.583
AIR			
TOTAL		4042.5	27.000
WATER 0.325		AIR 0.039	
CEMENT 100		TOTAL 149.7	
AGGREGATE 2.55		TOTAL 880.0	
* For use in concrete, the percentage of moisture in the aggregate must be determined and the amount of water added to the mixture must be adjusted accordingly.			
** For use in concrete, the percentage of moisture in the aggregate must be determined and the amount of water added to the mixture must be adjusted accordingly.			
*** For use in concrete, the percentage of moisture in the aggregate must be determined and the amount of water added to the mixture must be adjusted accordingly.			

SEE FORM NO. 1553  
REV. MAR. 1972

PLATE A13



REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD C-3)			
PROJECT NAME		SYMBOL	
		SERIAL NO.	
CONCRETE REQUIRED FOR		MEASURE NO.	
		T-8	
MATERIALS			
PORTLAND CEMENT 55-0-192		POZZOLON OR OTHER CEMENT	
TYPE I ADDITIONS		TYPE None	
BRAND AND MILL Marquette		SOURCE	
PORTLAND CEMENT AMOUNT		AMOUNT	
TYPE None		TYPE None	
AMOUNT		AMOUNT	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE Traprock		TYPE Traprock	
		SIZE 3/4 in.	
SOURCE Iron Mt. Trap Rock Co.		SOURCE Iron Mt. Trap Rock Co.	
MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGREGATE
PORTLAND CEMENT			
FINE AGGREGATE	Traprock	No. 4 - 200	Ap. 2.75
COARSE AGGREGATE A	Traprock	No. 4 - 3/4 in.	2.79
COARSE AGGREGATE B			
COARSE AGGREGATE C			
COARSE AGGREGATE D			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX BY WEIGHT	S. S. D. WEIGHTS (ONE CU YD BATCH - LB)	SOLID VOL (ONE CU YD - CU FT)
PORTLAND CEMENT	100	657	3.341
FINE AGGREGATE	2.30	1511	8.808
COARSE AGGREGATE A	2.43	1597	9.168
COARSE AGGREGATE B			
COARSE AGGREGATE C			
COARSE AGGREGATE D			
WATER	0.54	355	5.683
AIR			
TOTAL		4120	27.000
W. C. # 0.54		S. A. S. VOLUME 49	
SLUMP IN " 1.75		THEO. UNIT WT. LB. CU YD	
B. EEDING %		ACTUAL UNIT WT. LB. CU YD 152.6	
AIR CONTENT % 2.5		THEO. CEMENT FACT. LB. CU YD	
		ACTUAL CEMENT FACT. LB. CU YD 657	
1. Calculated on the basis of 2. Expressed as the percentage of mixing water separating from the concrete when tested by ASTM C-19 3. In the entire batch as mixed 4. In that portion of the concrete containing aggregate smaller than the 1/2 in. sieve * For other cement, pozzolan, second size of fine aggregate, as may be required REMARKS: Condition of mix, workability, plasticity, bleeding, etc.			

MS FORM NO 553  
REV. MAR 1972

PLATE A15

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS <small>(CRD-C-1)</small>			
PROJECT NAME		SYMBOL SERIAL NO.	DATE
CONCRETE REQUIRED FOR		MIXTURE NO. <div style="text-align: right;">T-9</div>	
MATERIALS			
PORTLAND CEMENT, NS 10792 TYPE <b>I</b> ADDITIONS BRAND AND MILL <b>Marquette</b>		POZZOLON OR OTHER CEMENT TYPE <b>None</b> SOURCE	
		AIR-ENT. MIXTURE TYPE <b>None</b> AMOUNT	
FINE AGGREGATE		FINE AGGREGATE	
TYPE <b>Traprock</b> SOURCE <b>Iron Mt. Traprock Co.</b>		TYPE <b>Traprock</b> SIZE <b>3/4 in.</b> SOURCE <b>Iron Mt. Traprock Co.</b>	
MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	AMOUNT BY WEIGHT
PORTLAND CEMENT			3.15
FINE AGGREGATE	CL-24 S-2	No. 4 - 200	2.75
COARSE AGGREGATE (A)	CL-24 G-2	No. 4 - 3/4 in.	2.79
COARSE AGGREGATE (B)			0.8
COARSE AGGREGATE (C)			0.3
COARSE AGGREGATE (D)			
MIXTURE DATA			
MATERIALS	MIX. BY WEIGHT	S. S. & WEIGHTS ONE CUBIC BATCH (LB.)	SOLID VOL. ONE CUBIC CU. FT.
PORTLAND CEMENT	1.00	886.5	4.510
FINE AGGREGATE	1.56	1384.3	8.067
COARSE AGGREGATE (A)	1.72	1521.6	8.740
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
WATER	0.40	354.6	5.683
AIR			
TOTAL		4147.0	27.000
W. C. R. <b>0.40</b>		S. A. S. VOLUME <b>48</b>	
SLUMP, IN. <b>2</b>		THEO. UNIT WT. (LB.) <b>153.6</b>	
BLEEDING, % <b>1.5</b>		ACTUAL UNIT WT. (LB.) <b>153.6</b>	
AIR-CONTENT, % <b>1.5</b>		THEO. CEMENT FACT. (LB./CU. YD.) <b>886.5</b>	
AIR-CONTENT, % <b>1.5</b>		ACTUAL CEMENT FACT. (LB./CU. YD.) <b>886.5</b>	
<small>1. Calculated on the basis of  2. Expressed as the percentage of mixing water separating from the concrete when tested by ASTM C 190  3. In the entire batch as mixed  4. In that portion of the concrete containing aggregate smaller than the 1 1/2 in. sieve  * For other cement, pozzolan, second size of fine aggregate, as may be required</small>			
REMARKS: Condition of mix, workability, plasticity, bleeding, etc.			

FD-3 FORM NO. 553  
REV. MAR.-1972

PLATE A16

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS ICRD-C-3			
PROJECT NAME		SYMBOL SERIAL NO	DATE
CONCRETE REQUIRED FOR		MIXTURE NO T-10	
MATERIALS			
PORTLAND CEMENT, SPEC 192 TYPE I ADDITIONS BRAND AND MILL Marquette		POZZOLON OR OTHER CEMENT TYPE None SOURCE	
		AIR ENIT ADMIXTURE TYPE Hunts AMOUNT 1.5 oz / cu yd	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE Sioux Quartzite		TYPE Sioux Quartzite SIZE 3/4 in.	
SOURCE L. G. Everist Quarry, S.D.		SOURCE L. G. Everist Quarry, S.D.	
MATERIALS	SAMPLE SERIAL NO	SIZE RANGE	COARSE AGGREGATE
PORTLAND CEMENT			
FINE AGGREGATE	CL-24 S-1	No. 4 - 200	Ap. 2.62
COARSE AGGREGATE A	CL-24 G-1	No. 4 - 3/4 in.	2.62
COARSE AGGREGATE B			
COARSE AGGREGATE C			
COARSE AGGREGATE D			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX. BY WEIGHT	S. S. T. WEIGHTS (LINE CUBIC BATCH) LB	SOLID VOL (LINE CUBIC) CU FT
PORTLAND CEMENT	100	385	1.959
FINE AGGREGATE	3.79	1458	8.920
COARSE AGGREGATE A	4.27	1645	10.059
COARSE AGGREGATE B			
COARSE AGGREGATE C			
COARSE AGGREGATE D			
WATER	0.72	277	4.442
AIR			1.620
TOTAL		3765	27.000
W. WT. 0.72		S. S. VOLUME 47	
VOLUME 1.5		THEORETICAL UNIT WT. LB / CU YD	
BETTING 5.4		ACTUAL UNIT WT. LB / CU YD 139.4	
AIR CONTENT 5.4		THEORETICAL CEMENT FACTOR LB / CU YD 385	
<p>1. Trial tested in the laboratory.</p> <p>2. Expressed as the percentage of mixing water separating from the concrete when tested by ASTM C 190.</p> <p>3. In the entire batch as mixed.</p> <p>4. In this portion of the concrete, assuming aggregate smaller than the 100 mesh sieve.</p> <p>5. For theoretical proportioning and size of the aggregate, as much as required.</p> <p>REMARKS: Additional notes or calculations should be included here.</p>			

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CR-103)	
PROJECT NAME	DATE
CONCRETE REQUIRED FOR	MIXTURE NO.
MATERIALS	
PORTLAND CEMENT 55-1192 TYPE I ADDITIONS BRAND AND MILL Marquette	POZZOLON OR OTHER CEMENT TYPE None SOURCE
AIR CONTENT ADJUSTMENT TYPE None AMOUNT	
FINE AGGREGATE	COARSE AGGREGATE
TYPE Sioux Quartzite SOURCE L. G. Everist Quarry, SD	TYPE Sioux Quartzite SIZE 3/4 in. SOURCE L. G. Everist Quarry, SD
MATERIALS	SAMPLE SERIAL NO.
SIZE RANGE	COARSE AGGREGATE
PORTLAND CEMENT	AIR CONTENT
FINE AGGREGATE	Ap. 2.62
COARSE AGGREGATE A	2.62
COARSE AGGREGATE B	1.0
COARSE AGGREGATE C	0.9
COARSE AGGREGATE D	
MIXTURE DATA	
MATERIALS	MIX BY WEIGHT
PORTLAND CEMENT	657
FINE AGGREGATE	2.19
COARSE AGGREGATE A	2.28
COARSE AGGREGATE B	1440
COARSE AGGREGATE C	1499
COARSE AGGREGATE D	8.808
WATER	9.168
AIR	0.54
TOTAL	355
TOTAL	5.683
TOTAL	3951
TOTAL	27.000
W. WT. 0.54	S. A. VOLUME 49
SLUMP IN IN. 2	THE UNIT WEIGHT 147.8
AIR CONTENT IN % 2.4	THE CEMENT FACTOR 657
1. If calculated on the basis of 2. Expresses as the percentage of mixing water separating from the concrete when tested by ASTM 3. In the entire batch as mixed 4. In that portion of the concrete mixture separating from the mass of the concrete 5. For the cement, pozzolan, and sand and fine aggregate as may be required REMARKS: Condition of mix, workability, plasticity, setting, etc.	

DESIGN NO. 501  
REV. MAR 1972

PLATE A18

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C-3)			
PROJECT NAME		SYMBOL	DATE
		SERIAL NO.	
CONCRETE REQUIRED FOR		MIXTURE NO. T-12	
MATERIALS			
PORTLAND CEMENT, SS-C-192		POZZOLON OR OTHER CEMENT	
TYPE I ADDITIONS		TYPE None	
BRAND AND MILL		SOURCE	
AIR-ENT. ADJUSTURE		TYPE None	
		AMOUNT	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE Sioux Quartzite		TYPE Sioux Quartzite	
		SIZE 3/4 in.	
SOURCE		SOURCE	
MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	CLARKE ANAL.
PORTLAND CEMENT			
FINE AGGREGATE	CL-24 S-1	No. 4 - 200	2.62
COARSE AGGREGATE A	CL-24 G-1	No. 4 - 3/4 in.	2.62
COARSE AGGREGATE B			
COARSE AGGREGATE C			
COARSE AGGREGATE D			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX BY WEIGHT	S. G. WEIGHTS OF BATCH LB.	S. G. VOLUME ONE CYCLO CU. FT.
PORTLAND CEMENT	1.00	886.5	4.401
FINE AGGREGATE	1.43	1272.1	7.781
COARSE AGGREGATE A	1.68	1493.5	9.135
COARSE AGGREGATE B			
COARSE AGGREGATE C			
COARSE AGGREGATE D			
WATER	0.40	354.6	5.683
AIR			
TOTAL		4006.7	27.000
W. W. T.	0.40	S. G. VOLUME 46	
SLUMP IN "	1.5	THEO. UNIT WT. LB. CU. FT.	
BLEEDING %		ACTUAL UNIT WT. LB. CU. FT. 148.4	
AIR CONTENT %	2.2	THEO. CEMENT FACT. LB. CU. FT.	
AIR CONTENT %		ACTUAL CEMENT FACT. LB. CU. FT. 886.5	
1. Calculated on the basis of 2. Expressed as the percentage of mixing water separating from the concrete when tested by A. M. 114 3. In the entire batch as mixed 4. In that portion of the concrete containing aggregate smaller than the No. 10 sieve * For other cement, pozzolans, second size of fine aggregate, etc. may be required			
REMARKS: Condition of mix, workability, plasticity, bleeding, etc.			

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C-3)			
PROJECT NAME		SYMBOL SERIAL NO	
CONCRETE REQUIRED FOR		DATE	
		MIXTURE NO T-13	
MATERIALS			
PORTLAND CEMENT, SS-C-192 TYPE II ADDITIONS BRAND AND MILL		POZZOLON OR OTHER CEMENT TYPE SOURCE	
		AIR-ENT ADMIXTURE TYPE Lab Stock AMOUNT <sup>1</sup> NVR	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE Granite		TYPE Granite SIZE 1-1/2 in	
SOURCE		SOURCE	
MATERIALS	SAMPLE SERIAL NO	SIZE RANGE	COARSE AGGR. %
PORTLAND CEMENT	RC-705		
FINE AGGREGATE	LA-2 S-1	No. 4 - 200	
COARSE AGGREGATE A	LA-2 G-2	No. 4 - 3/4 in.	55
COARSE AGGREGATE B	LA-2 G-3	3/4 - 1-1/2 in.	45
COARSE AGGREGATE C			
COARSE AGGREGATE D			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX BY WEIGHT	SAND WEIGHT ONE CUBIC FOOT	TOTAL WEIGHT
PORTLAND CEMENT	100	517.0	2.630
FINE AGGREGATE	2.43	1258	7.815
COARSE AGGREGATE A	1.92	993	5.936
COARSE AGGREGATE B	1.56	809	4.856
COARSE AGGREGATE C			
COARSE AGGREGATE D			
WATER	0.50	259	4.143
AIR			1.620
TOTAL		3836	27.000
W.C. WT. 0.50		S.A. VOLUME 32	
SLUMP IN * 2.5		THEO. UNIT WT. LB. CU. FT.	
BEEIDING IN *		ACTUAL UNIT WT. LB. CU. FT. 142.1	
AIR CONTENT IN * 4.7		THEO. CEMENT FACT. LB. CU. YD.	
		ACTUAL CEMENT FACT. LB. CU. YD. 517	
<sup>1</sup> Expressed in the basis of <sup>2</sup> Expressed as the percentage of mixing water separating from the concrete when tested by ASTM D <sup>3</sup> In the entire batch as mixed <sup>4</sup> In that portion of the concrete containing aggregate smaller than the 1 1/2 in. sieve <sup>5</sup> For other cement, pozzolan, or sand size of fine aggregate, as may be required.			
REMARKS: Condition of mix, workability, plasticity, bleeding, etc.			

SPR FORM NO. 541  
REV. MAR. 1972

PLATE A20

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C-3)			
PROJECT NAME		SYMBOL SERIAL NO	
DATE			
CONCRETE REQUIRED FOR		MIXTURE NO T-14	
MATERIALS			
PORTLAND CEMENT, SS-C-194 TYPE II ADDITIONS BRAND AND MILL		POZZOLON OR OTHER CEMENT TYPE None SOURCE	
		AIR-ENT ADMIXTURE TYPE Lab Stock AMOUNT NVR	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE Granite		TYPE Granite SIZE 1-1/2 in.	
SOURCE		SOURCE	
MATERIALS	SAMPLE SERIAL NO	SIZE RANGE	FINE AGGREGATE BULKING OR SST
PORTLAND CEMENT	RC-705		
FINE AGGREGATE	LA-2 S-1	No. 4 - 200	2.58
COARSE AGGREGATE A	LA-2 G-2	No. 4 - 3/4 in.	2.68
COARSE AGGREGATE B	LA-2 G-3	3/4 - 1-1/2 in.	2.67
COARSE AGGREGATE C			
COARSE AGGREGATE D			
MIXTURE DATA		PRELIMINARY DATA	
MATERIALS	MIX BY WEIGHT	S. S. D. WEIGHTS NEEDED RATIO (LB)	VOLUME ONE CYCLO (CU FT)
PORTLAND CEMENT	100	517.0	2.630
FINE AGGREGATE	2.38	1230	7.641
COARSE AGGREGATE A	1.88	970	5.803
COARSE AGGREGATE B	1.54	794	4.748
COARSE AGGREGATE C			
COARSE AGGREGATE D			
WATER	0.55	284	4.558
AIR	4		1.620
		3795	27.000
WATER - 2.55		AIR - 0.02	
S. S. D. - 4		THEORETICAL WEIGHT -	
WATER - 4.6		ACTUAL WEIGHT - 140.6	
AIR - 4.6		THEORETICAL WEIGHT -	
AIR - 4.6		ACTUAL WEIGHT - 517	
<p>1. All calculations are based on the assumption that the concrete is made from the materials listed in the report when tested to CRD-C-3.</p> <p>2. The values are the percentages of materials by weight of the concrete as made.</p> <p>3. The values are the percentages of materials by weight of the concrete as made.</p> <p>4. The values are the percentages of materials by weight of the concrete as made.</p> <p>5. The values are the percentages of materials by weight of the concrete as made.</p> <p>6. The values are the percentages of materials by weight of the concrete as made.</p> <p>7. The values are the percentages of materials by weight of the concrete as made.</p> <p>8. The values are the percentages of materials by weight of the concrete as made.</p> <p>9. The values are the percentages of materials by weight of the concrete as made.</p> <p>10. The values are the percentages of materials by weight of the concrete as made.</p>			

REVISION NO. 1  
BY: M. H. H.

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS			
PROJECT NAME		SYMBOL	DATE
CONCRETE REQUIRED FOR		SEMI-FIN	MIXTURE NO. T-15
MATERIALS			
PORTLAND CEMENT SOURCE		PORTLAND CEMENT	
TYPE II ADDITIONS		TYPE	
BRAND AND MILL		SOURCE	
		Lab Stock	
		AMOUNT NVR	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE Granite		TYPE Slag	
SOURCE		SOURCE	
		No. 1-1/2	
MATERIALS		SAMPLE SERIAL NO.	
PORTLAND CEMENT		RC-705	
FINE AGGREGATE		No. 4 - 200	
COARSE AGGREGATE A		No. 4 - 3/4 in	
COARSE AGGREGATE B		3/4 - 1-1/2 in	
COARSE AGGREGATE C			
COARSE AGGREGATE D			
COARSE AGGREGATE E			
COARSE AGGREGATE F			
COARSE AGGREGATE G			
COARSE AGGREGATE H			
COARSE AGGREGATE I			
COARSE AGGREGATE J			
COARSE AGGREGATE K			
COARSE AGGREGATE L			
COARSE AGGREGATE M			
COARSE AGGREGATE N			
COARSE AGGREGATE O			
COARSE AGGREGATE P			
COARSE AGGREGATE Q			
COARSE AGGREGATE R			
COARSE AGGREGATE S			
COARSE AGGREGATE T			
COARSE AGGREGATE U			
COARSE AGGREGATE V			
COARSE AGGREGATE W			
COARSE AGGREGATE X			
COARSE AGGREGATE Y			
COARSE AGGREGATE Z			
COARSE AGGREGATE AA			
COARSE AGGREGATE AB			
COARSE AGGREGATE AC			
COARSE AGGREGATE AD			
COARSE AGGREGATE AE			
COARSE AGGREGATE AF			
COARSE AGGREGATE AG			
COARSE AGGREGATE AH			
COARSE AGGREGATE AI			
COARSE AGGREGATE AJ			
COARSE AGGREGATE AK			
COARSE AGGREGATE AL			
COARSE AGGREGATE AM			
COARSE AGGREGATE AN			
COARSE AGGREGATE AO			
COARSE AGGREGATE AP			
COARSE AGGREGATE AQ			
COARSE AGGREGATE AR			
COARSE AGGREGATE AS			
COARSE AGGREGATE AT			
COARSE AGGREGATE AU			
COARSE AGGREGATE AV			
COARSE AGGREGATE AW			
COARSE AGGREGATE AX			
COARSE AGGREGATE AY			
COARSE AGGREGATE AZ			
COARSE AGGREGATE BA			
COARSE AGGREGATE BB			
COARSE AGGREGATE BC			
COARSE AGGREGATE BD			
COARSE AGGREGATE BE			
COARSE AGGREGATE BF			
COARSE AGGREGATE BG			
COARSE AGGREGATE BH			
COARSE AGGREGATE BI			
COARSE AGGREGATE BJ			
COARSE AGGREGATE BK			
COARSE AGGREGATE BL			
COARSE AGGREGATE BM			
COARSE AGGREGATE BN			
COARSE AGGREGATE BO			
COARSE AGGREGATE BP			
COARSE AGGREGATE BQ			
COARSE AGGREGATE BR			
COARSE AGGREGATE BS			
COARSE AGGREGATE BT			
COARSE AGGREGATE BU			
COARSE AGGREGATE BV			
COARSE AGGREGATE BW			
COARSE AGGREGATE BX			
COARSE AGGREGATE BY			
COARSE AGGREGATE BZ			
COARSE AGGREGATE CA			
COARSE AGGREGATE CB			
COARSE AGGREGATE CC			
COARSE AGGREGATE CD			
COARSE AGGREGATE CE			
COARSE AGGREGATE CF			
COARSE AGGREGATE CG			
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COARSE AGGREGATE CK			
COARSE AGGREGATE CL			
COARSE AGGREGATE CM			
COARSE AGGREGATE CN			
COARSE AGGREGATE CO			
COARSE AGGREGATE CP			
COARSE AGGREGATE CQ			
COARSE AGGREGATE CR			
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COARSE AGGREGATE CU			
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COARSE AGGREGATE CY			
COARSE AGGREGATE CZ			
COARSE AGGREGATE DA			
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COARSE AGGREGATE DE			
COARSE AGGREGATE DF			
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COARSE AGGREGATE DI			
COARSE AGGREGATE DJ			
COARSE AGGREGATE DK			
COARSE AGGREGATE DL			
COARSE AGGREGATE DM			
COARSE AGGREGATE DN			
COARSE AGGREGATE DO			
COARSE AGGREGATE DP			
COARSE AGGREGATE DQ			
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COARSE AGGREGATE DT			
COARSE AGGREGATE DU			
COARSE AGGREGATE DV			
COARSE AGGREGATE DW			
COARSE AGGREGATE DX			
COARSE AGGREGATE DY			
COARSE AGGREGATE DZ			
COARSE AGGREGATE EA			
COARSE AGGREGATE EB			
COARSE AGGREGATE EC			
COARSE AGGREGATE ED			
COARSE AGGREGATE EE			
COARSE AGGREGATE EF			
COARSE AGGREGATE EG			
COARSE AGGREGATE EH			
COARSE AGGREGATE EI			
COARSE AGGREGATE EJ			
COARSE AGGREGATE EK			
COARSE AGGREGATE EL			
COARSE AGGREGATE EM			
COARSE AGGREGATE EN			
COARSE AGGREGATE EO			
COARSE AGGREGATE EP			
COARSE AGGREGATE EQ			
COARSE AGGREGATE ER			
COARSE AGGREGATE ES			
COARSE AGGREGATE ET			
COARSE AGGREGATE EU			
COARSE AGGREGATE EV			
COARSE AGGREGATE EW			
COARSE AGGREGATE EX			
COARSE AGGREGATE EY			
COARSE AGGREGATE EZ			
COARSE AGGREGATE FA			
COARSE AGGREGATE FB			
COARSE AGGREGATE FC			
COARSE AGGREGATE FD			
COARSE AGGREGATE FE			
COARSE AGGREGATE FF			
COARSE AGGREGATE FG			
COARSE AGGREGATE FH			
COARSE AGGREGATE FI			
COARSE AGGREGATE FJ			
COARSE AGGREGATE FK			
COARSE AGGREGATE FL			
COARSE AGGREGATE FM			
COARSE AGGREGATE FN			
COARSE AGGREGATE FO			
COARSE AGGREGATE FP			
COARSE AGGREGATE FQ			
COARSE AGGREGATE FR			
COARSE AGGREGATE FS			
COARSE AGGREGATE FT			
COARSE AGGREGATE FU			
COARSE AGGREGATE FV			
COARSE AGGREGATE FW			
COARSE AGGREGATE FX			
COARSE AGGREGATE FY			
COARSE AGGREGATE FZ			
COARSE AGGREGATE GA			
COARSE AGGREGATE GB			
COARSE AGGREGATE GC			
COARSE AGGREGATE GD			
COARSE AGGREGATE GE			
COARSE AGGREGATE GF			
COARSE AGGREGATE GG			
COARSE AGGREGATE GH			
COARSE AGGREGATE GI			
COARSE AGGREGATE GJ			
COARSE AGGREGATE GK			
COARSE AGGREGATE GL			
COARSE AGGREGATE GM			
COARSE AGGREGATE GN			
COARSE AGGREGATE GO			
COARSE AGGREGATE GP			
COARSE AGGREGATE GQ			
COARSE AGGREGATE GR			
COARSE AGGREGATE GS			
COARSE AGGREGATE GT			
COARSE AGGREGATE GU			
COARSE AGGREGATE GV			
COARSE AGGREGATE GW			
COARSE AGGREGATE GX			
COARSE AGGREGATE GY			
COARSE AGGREGATE GZ			
COARSE AGGREGATE HA			
COARSE AGGREGATE HB			
COARSE AGGREGATE HC			
COARSE AGGREGATE HD			
COARSE AGGREGATE HE			
COARSE AGGREGATE HF			
COARSE AGGREGATE HG			
COARSE AGGREGATE HH			
COARSE AGGREGATE HI			
COARSE AGGREGATE HJ			
COARSE AGGREGATE HK			
COARSE AGGREGATE HL			
COARSE AGGREGATE HM			
COARSE AGGREGATE HN			
COARSE AGGREGATE HO			
COARSE AGGREGATE HP			
COARSE AGGREGATE HQ			
COARSE AGGREGATE HR			
COARSE AGGREGATE HS			
COARSE AGGREGATE HT			
COARSE AGGREGATE HU			
COARSE AGGREGATE HV			
COARSE AGGREGATE HW			
COARSE AGGREGATE HX			
COARSE AGGREGATE HY			
COARSE AGGREGATE HZ			
COARSE AGGREGATE IA			
COARSE AGGREGATE IB			
COARSE AGGREGATE IC			
COARSE AGGREGATE ID			
COARSE AGGREGATE IE			
COARSE AGGREGATE IF			
COARSE AGGREGATE IG			
COARSE AGGREGATE IH			
COARSE AGGREGATE II			
COARSE AGGREGATE IJ			
COARSE AGGREGATE IK			
COARSE AGGREGATE IL			
COARSE AGGREGATE IM			
COARSE AGGREGATE IN			
COARSE AGGREGATE IO			
COARSE AGGREGATE IP			
COARSE AGGREGATE IQ			
COARSE AGGREGATE IR			
COARSE AGGREGATE IS			
COARSE AGGREGATE IT			
COARSE AGGREGATE IU			
COARSE AGGREGATE IV			
COARSE AGGREGATE IW			
COARSE AGGREGATE IX			
COARSE AGGREGATE IY			
COARSE AGGREGATE IZ			

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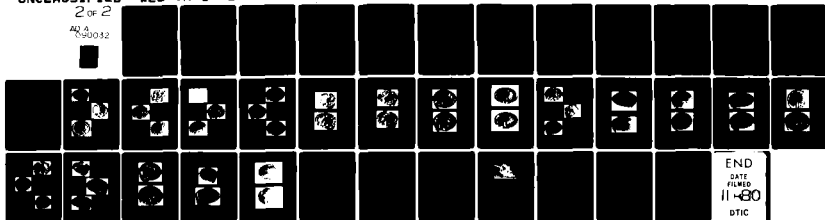
ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS F/6 11/2  
MAINTENANCE AND PRESERVATION OF CONCRETE STRUCTURES. REPORT 3. --ETC(U)  
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REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C 3)			
PROJECT NAME		SYMBOL SERIAL NO.	DATE
CONCRETE REQUIRED FOR		MIXTURE NO. <b>T-16</b>	
MATERIALS			
PORTLAND CEMENT, SS-C-192, TYPE: <b>II</b> ADDITIONS BRAND AND MILL		POZZOLON OR OTHER CEMENT TYPE SOURCE	AIR ENT. ADMIXTURE TYPE <b>Lab Stock</b> AMOUNT: <b>NVR</b>
FINE AGGREGATE		COARSE AGGREGATE	
TYPE <b>Granite</b>		TYPE <b>Slag</b> SIZE <b>1-1/2 in.</b>	
SOURCE		SOURCE	
MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR (%)
PORTLAND CEMENT	RC-705		
FINE AGGREGATE	LA-2 S-1	No. 4 - 200	
COARSE AGGREGATE (A)	LA-2 G-4	No. 4 - 3/4 in.	35
COARSE AGGREGATE (B)	LA-2 G-5	3/4 - 1-1/2 in.	65
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX. BY WEIGHT	S. S. D. WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)
PORTLAND CEMENT	1.00	517.0	2.630
FINE AGGREGATE	2.30	1189	7.385
COARSE AGGREGATE (A)	1.05	544	3.877
COARSE AGGREGATE (B)	1.96	1011	7.200
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
WATER	0.55	284	4.558
AIR			1.350
TOTAL		3545	27.000
W/C (WT) <b>0.55</b>		S/A % VOLUME <b>40</b>	
SLUMP (IN) <b>3.75</b>		THEO UNIT WT (LB CU FT)	
BLEEDING (%) <b>2</b>		ACTUAL UNIT WT (LB CU FT) <b>131.3</b>	
AIR CONTENT (%) <b>6.0</b>		THEO CEMENT FACT (LB CU YD)	
		ACTUAL CEMENT FACT (LB CU YD) <b>517</b>	
1 Calculated on the basis of 2 Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9 3 In the entire batch as mixed. 4 In that portion of the concrete containing aggregate smaller than the 1-1/2-in. sieve * For "other cement," pozzolan, second size of fine aggregate, as may be required			
REMARKS: Condition of mix, workability, plasticity, bleeding, etc.			

WS FORM NO. 553  
REV MAR 1972

PLATE A23

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C 3)			
PROJECT NAME		SYMBOL SERIAL NO.	DATE
CONCRETE REQUIRED FOR		MIXTURE NO <b>T-17</b>	
MATERIALS			
PORTLAND CEMENT SS-C-192. TYPE <b>I</b> ADDITIONS BRAND AND MILL <b>Marquette</b>		POZZOLON OR OTHER CEMENT TYPE SOURCE	
		AIR-ENT ADMIXTURE TYPE <b>Hunts</b> AMOUNT <sup>1</sup> <b>Air-In.</b> <b>1.5 fl oz / cu yd</b>	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE <b>Limestone</b>		TYPE <b>Limestone</b> SIZE <b>3/4 in.</b>	
SOURCE		SOURCE	
MATERIALS	SAMPLE SERIAL NO	SIZE RANGE	COARSE AGGR (%)
PORTLAND CEMENT			
FINE AGGREGATE	CL-2 MS-1(2)	No. 4 - 200	
COARSE AGGREGATE (A)	CL-2 G-1(3)	No. 4 - 3/4 in.	
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX BY WEIGHT	S. S. D. WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)
PORTLAND CEMENT	1.00	395	2.011
FINE AGGREGATE	3.91	1543	9.157
COARSE AGGREGATE (A)	4.44	1753	10.327
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
WATER	0.72	285	4.560
AIR			0.945
TOTAL		3976	27.000
W/C (WT) <b>0.72</b>		S/A % VOLUME <b>47</b>	
SLUMP (IN) <sup>2</sup> <b>2</b>		THEO UNIT WT (LB CU FT)	
BLEEDING (IN) <sup>2</sup>		ACTUAL UNIT WT (LB CU FT) <b>147.3</b>	
AIR CONTENT (IN) <sup>3</sup> <b>3.5</b>		THEO CEMENT FACT (LB CU YD)	
AIR CONTENT (IN) <sup>4</sup>		ACTUAL CEMENT FACT (LB CU YD) <b>395</b>	
<sup>1</sup> Calculated on the basis of <sup>2</sup> Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9 <sup>3</sup> In the entire batch as mixed. <sup>4</sup> In that portion of the concrete containing aggregate smaller than the 1-1/2-in. sieve <sup>5</sup> For "other cement," pozzolan, second size of fine aggregate, as may be required			
REMARKS Condition of mix, workability, plasticity, bleeding, etc			

903 FORM NO 553  
REV MAR 1979

PLATE A24

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C 3)			
PROJECT NAME		SYMBOL SERIAL NO	DATE
CONCRETE REQUIRED FOR		MIXTURE NO T-18	
MATERIALS			
PORTLAND CEMENT, SS-C-182 TYPE I ADDITIONS BRAND AND MILL Marquette		POZZOLON OR OTHER CEMENT TYPE SOURCE	
		AIR ENT. ADMIXTURE TYPE Hunts AMOUNT <sup>1</sup> Air-In.	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE Siliceous Gravel		TYPE Siliceous Gravel size 1-1/2 in.	
SOURCE Libby Dam		SOURCE Libby Dam	
MATERIALS	SAMPLE SERIAL NO	SIZE RANGE	COARSE AGGR (%)
PORTLAND CEMENT Fly Ash MBL-80			
FINE AGGREGATE			
COARSE AGGREGATE (A)			
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX. BY WEIGHT	S. S. D. WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL. <sup>†</sup> ONE CU YD (CU FT)
PORTLAND CEMENT	100	447	
Fly Ash	0.42	189	
MBL-80 (WAA)		32 fl oz	
FINE AGGREGATE	3.56	1591	
COARSE AGGREGATE (A)	3.25	1451	
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
WATER	0.43	275	
AIR			
TOTAL		3953	
W. C. R. T. 0.43**		S. A. S. VOLUME 52	
SLUMP IN # 5		THEO. UNIT WT. (LB CU FT)	
BLEEDING %		ACTUAL UNIT WT. (LB CU FT) 146.4	
AIR CONTENT % 4.1		THEO. CEMENT FACT (LB CU YD)	
AIR CONTENT %		ACTUAL CEMENT FACT (LB CU YD) 636	
<sup>1</sup> Calculated on the basis of <sup>2</sup> Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9 <sup>3</sup> In the entire batch as mixed <sup>4</sup> In that portion of the concrete containing aggregate smaller than the 1-1/2-in. sieve <sup>5</sup> For "other cement," pozzolan, second size of fine aggregate, as may be required <b>REMARKS</b> Condition of mix, workability, plasticity, bleeding, etc. <b>**</b> Water/(Cement + Fly Ash) <b>†</b> Specific gravity of the aggregates is not available.			

808 FORM NO 551  
REV MAR 1972

PLATE A25

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C 3)			
PROJECT NAME		SYMBOL	DATE
CONCRETE REQUIRED FOR		SERIAL NO.	MIXTURE NO <b>T-26</b>
MATERIALS			
PORTLAND CEMENT, SS-C-192. TYPE <b>I</b> ADDITIONS: BRAND AND MILL: <b>Marquette</b>		POZZOLON OR OTHER CEMENT: TYPE <b>Fly Ash</b> SOURCE	
		AIR-ENT. ADMIXTURE TYPE <b>None</b> AMOUNT	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE <b>Limestone</b>		TYPE <b>Limestone</b> SIZE	
SOURCE		SOURCE	
MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR. (%) BULK SP. GR. (SSD) ABSORP.
PORTLAND CEMENT			3.15
Fly Ash			2.50
FINE AGGREGATE	CL-2 MS-1(2)	No. 4 - 200	2.70 0.7
COARSE AGGREGATE (A)	CL-2 G-1(3)	No. 4 - 3/4 in.	2.72 0.4
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
MIXTURE DATA			SPECIMEN DATA
MATERIALS	MIX. BY WEIGHT	S. S. D. WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)
PORTLAND CEMENT	1.00	493	2.506
Fly Ash	0.26	130	0.835
FINE AGGREGATE	3.06	1508	8.951
COARSE AGGREGATE (A)	3.15	1581	9.317
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
WATER	0.54	336	5.391
AIR			
TOTAL		4048	27.000
W/C (WT) <b>0.54**</b>		S/A, % VOLUME <b>49</b>	
SLUMP (IN) <b>6</b>		THEO. UNIT WT (LB CU FT)	
BLEEDING (%)		ACTUAL UNIT WT (LB CU FT) <b>149.9</b>	
AIR CONTENT (%) <b>0.8</b>		THEO. CEMENT FACT (LB CU YD)	
AIR CONTENT (%)		ACTUAL CEMENT FACT (LB CU YD) <b>623</b>	
1 Calculated on the basis of 2 Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9 3 In the entire batch as mixed 4 In that portion of the concrete containing aggregate smaller than the 1-1/2-in. sieve 5 For "other cement," pozzolan, second size of fine aggregate, as may be required.			
REMARKS: Condition of mix, workability, plasticity, bleeding, etc.			
** <b>Water/(Cement + Fly Ash)</b>			

WSR FORM NO 553  
REV MAR 1972

PLATE A26

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C 3)			
PROJECT NAME		SYMBOL	DATE
		SERIAL NO	
CONCRETE REQUIRED FOR			MIXTURE NO <b>F-1</b>
MATERIALS			
PORTLAND CEMENT, SS-C-192, TYPE <b>I</b> ADDITIONS BRAND AND MILL <b>Marquette</b>		POZZOLON OR OTHER CEMENT TYPE <b>None</b> SOURCE	AIR-ENT ADMIXTURE TYPE <b>Hunts</b> AMOUNT <b>Air-In.</b>
FINE AGGREGATE		COARSE AGGREGATE	
TYPE <b>Limestone</b> SOURCE		TYPE <b>Limestone</b> SIZE <b>3/4 in.</b> SOURCE	
MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR. 1" BULK SP GR. SSD ABSORP.
PORTLAND CEMENT			3.15
Steel Fibers		.010x.022x1/2 in.	7.65
FINE AGGREGATE	CL-2 MS-1(2)	No. 4 - 200	2.70
COARSE AGGREGATE (A)	CL-2 G-1(3)	No. 4 - 3/4 in.	2.72
COARSE AGGREGATE (B)			0.7
COARSE AGGREGATE (C)			0.4
COARSE AGGREGATE (D)			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX. BY WEIGHT	S. S. D. WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)
PORTLAND CEMENT	1.00	385	1.959
Fibers	0.31	121	0.254
FINE AGGREGATE	3.90	1503	8.920
COARSE AGGREGATE (A)	4.32	1664	9.805
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
WATER	0.72	277	4.442
AIR			1.620
TOTAL		3950	27.000
W/C (WT) <b>0.72</b>		S/A % VOLUME <b>47</b>	
SLUMP (IN) <b>0.5</b>		THEO UNIT WT (LB CU FT)	
BLEEDING (%) <b>2</b>		ACTUAL UNIT WT (LB CU FT) <b>146.3</b>	
AIR CONTENT (%) <b>6.6</b>		THEO CEMENT FACT (LB CU YD)	
		ACTUAL CEMENT FACT (LB CU YD) <b>385</b>	
1 Calculated on the basis of 2 Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9 3 In the entire batch as mixed. 4 In that portion of the concrete containing aggregate smaller than the 1-1/2-in. sieve * For "other cement," pozzolan, second size of fine aggregate, as may be required			
REMARKS: Condition of mix, workability, plasticity, bleeding, etc			



PROJECT NAME		SYMBOL		DATE									
CONCRETE REQUIRED FOR		SERIAL NO		MIXTURE NO									
F-3													
MATERIALS													
PORTLAND CEMENT, SS-C-192		POZZOLON OR OTHER CEMENT		AIR ENT. ADMIXTURE									
TYPE I ADDITIONS		TYPE None		TYPE Lab Stock									
BRAND AND MILL Marquette		SOURCE		AMOUNT NVR									
FINE AGGREGATE			COARSE AGGREGATE										
TYPE Limestone			TYPE Limestone										
SOURCE			SIZE 3/4 in.										
MATERIALS		SAMPLE SERIAL NO		SIZE RANGE									
PORTLAND CEMENT				COARSE AGGR.									
FINE AGGREGATE		Steel Fibers		BULK SPECIFIC GR									
COARSE AGGREGATE A		CL-2 MS-1(2)		ABSORP									
COARSE AGGREGATE B		CL-2 G-1(3)											
COARSE AGGREGATE C		No. 4 - 200											
COARSE AGGREGATE D		No. 4 - 3/4 in.											
MIXTURE DATA				SPECIMEN DATA									
MATERIALS		MIX BY WEIGHT		S & S C WEIGHTS ONE CYCLO BATCH		SOLID VOL ONE CYCLO		CYLINDERS			BEAMS		
								SIZE			SIZE		
								NO			AGE		
								PS			PS		
PORTLAND CEMENT		100		715		3.637							
WRA				51 oz									
Steel Fibers		0.17		120		0.251							
FINE AGGREGATE		2.03		1450		8.606							
COARSE AGGREGATE A		1.96		1400		8.248							
COARSE AGGREGATE B													
COARSE AGGREGATE C													
COARSE AGGREGATE D													
WATER		0.41		293		4.696							
AIR						1.562							
TOTAL				3978		27.000							
W. R. 0.41						50							
SLUMP IN. 1.0													
SECELEND 147.3													
AIR CONTENT 4.0													
AIR CONTENT 715													
1. Not stated in the table of 2. Expressed as the percentage of mixing water separating from the concrete when tested by T.M.C. 9 3. In the entire batch as mixed 4. That portion of the concrete containing aggregate smaller than the 1/2 in. sieve 5. For water cement, pozzolan, second size of fine aggregate, as may be required 6. M.P.S.A. Condition of mix, workability, plasticity, bleeding, etc.													

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C 3)			
PROJECT NAME:		SYMBOL:	DATE:
CONCRETE REQUIRED FOR:		SERIAL NO.:	MIXTURE NO.: <b>F-4</b>
MATERIALS			
PORTLAND CEMENT, SS-C-192. TYPE: <b>I</b> ADDITIONS: BRAND AND MILL: <b>Marquette</b>		POZZOLON OR OTHER CEMENT: TYPE: <b>None</b> SOURCE:	
		AIR-ENT. ADMIXTURE: TYPE: <b>Hunts</b> AMOUNT: <b>Air-In.</b>	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE: <b>Limestone</b> SOURCE:		TYPE: <b>Limestone</b> <b>SIZE 3/4 in.</b> SOURCE:	
MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR. (%)
PORTLAND CEMENT			3.15
USS Fibercon Steel Fibers		.010x.022x1 in.	7.65
FINE AGGREGATE	CL-2 MS-1(2)	No. 4 - 200	2.70
COARSE AGGREGATE (A)	CL-2 G-1 (3)	No. 4 - 3/4 in.	2.72
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX. BY WEIGHT	S. S. D. WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)
PORTLAND CEMENT	1.00	385	1.959
Steel Fibers	0.31	121	0.254
FINE AGGREGATE	4.20	1503	8.920
COARSE AGGREGATE (A)	4.32	1664	9.805
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
WATER	0.72	277	4.442
AIR			1.620
TOTAL		3950	27.000
W/C (WT)	0.72	S/A % VOLUME 47	
SLUMP (IN)	0.25	THEO. UNIT WT (LB. CU YD)	
BLEEDING (%)		ACTUAL UNIT WT (LB. CU YD) 146.3	
AIR CONTENT (%)	6.6	THEO. CEMENT FACT (LB. CU YD)	
AIR CONTENT (%)		ACTUAL CEMENT FACT (LB. CU YD) 385	
1 Calculated on the basis of 2 Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9. 3 In the entire batch as mixed. 4 In that portion of the concrete containing aggregate smaller than the 1-1/2-in. sieve. * For "other cement," pozzolan, second size of fine aggregate, as may be required.			
REMARKS: Condition of mix, workability, plasticity, bleeding, etc.			

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REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C 3)			
PROJECT NAME		SYMBOL SERIAL NO.	DATE
CONCRETE REQUIRED FOR		MIXTURE NO. <b>F-5</b>	
MATERIALS			
PORTLAND CEMENT, 5-11-192. TYPE <b>I</b> ADDITIONS BRAND AND MILL <b>Marquette</b>		POZZOLON OR OTHER CEMENT TYPE <b>None</b> SOURCE	
		AIR-ENT ADMIXTURE TYPE <b>None</b> AMOUNT <sup>1</sup>	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE <b>Limestone</b>		TYPE <b>Limestone</b> SIZE <b>3/4 in.</b>	
SOURCE		SOURCE	
MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR. (%)
PORTLAND CEMENT			BULK SP GR (SSD)
USS Fibercon	Steel Fibers	.010x.022x1 in.	3.15
FINE AGGREGATE	CL-2 MS-1(2)	No. 4 - 200	7.65
COARSE AGGREGATE (A)	CL-2 G-1(3)	No. 4 - 3/4 in.	2.70
COARSE AGGREGATE (B)			2.72
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX. BY WEIGHT	S. S. D. WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)
PORTLAND CEMENT	1.00	657	3.341
Steel Fibers	0.19	128	0.267
FINE AGGREGATE	2.26	1484	8.808
COARSE AGGREGATE (A)	2.30	1511	8.901
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
WATER	0.54	355	5.683
AIR			
TOTAL		4135	27.000
W/C (WT)		0.54	S/A, VOLUME 49
SLUMP (IN) <sup>2</sup>		1.25	THEO. UNIT WT (LB/CU FT)
BLEEDING (%) <sup>3</sup>			ACTUAL UNIT WT (LB/CU FT) 153.1
AIR CONTENT (%) <sup>4</sup>		1.8	THEO. CEMENT FACT (LB/CU YD)
			ACTUAL CEMENT FACT (LB/CU YD) 657
<sup>1</sup> Calculated on the basis of <sup>2</sup> Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9. <sup>3</sup> In the entire batch as mixed. <sup>4</sup> In that portion of the concrete containing aggregate smaller than the 1-1/2-in. sieve. <sup>5</sup> For "other cement," pozzolan, second size of fine aggregate, as may be required.			
REMARKS: Condition of mix, workability, plasticity, bleeding, etc.			

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C 3)			
PROJECT NAME		SYMBOL	DATE
CONCRETE REQUIRED FOR		SERIAL NO.	MIXTURE NO.
			F-6
MATERIALS			
PORTLAND CEMENT, S <sub>1</sub> -C-192		POZZOLON OR OTHER CEMENT	
TYPE I ADDITIONS		TYPE None	
BRAND AND MILL Marquette		SOURCE	
AIR-ENT ADMIXTURE		TYPE NVR	
		AMOUNT Lab Stock	
FINE AGGREGATE		COARSE AGGREGATE	
TYPE Limestone		TYPE Limestone	
		SIZE 3/4 in.	
SOURCE		SOURCE	
MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR. 1"
PORTLAND CEMENT	Type I		
Fibers		.010x.022x1 in.	
FINE AGGREGATE	CL-2 MS-1(2)	No. 4 - 200	
COARSE AGGREGATE (A)	CL-2 G-1(3)	No. 4 - 3/4 in.	
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
MIXTURE DATA		SPECIMEN DATA	
MATERIALS	MIX. BY WEIGHT	S. S. D. WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)
PORTLAND CEMENT	1.00	720.8	3.667
HPS-R		51.0 oz	
FINE AGGREGATE	2.03	1461.6	8.675
COARSE AGGREGATE (A)	1.96	1411.1	8.314
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C) Fibers	0.17	120.3	0.252
COARSE AGGREGATE (D)			
WATER	0.41	295.3	4.732
AIR			1.360
TOTAL		4009.1	27.000
W C R T 0.41		S. A. S VOLUME 50	
SLUMP (IN) 2		THEO. UNIT WT (LB CU FT)	
BLEEDING (IN) 2		ACTUAL UNIT WT (LB CU FT) 148.5	
AIR CONTENT (%) 5.0		THEO. CEMENT FACT (LB CU YD)	
AIR CONTENT (%) 5.0		ACTUAL CEMENT FACT (LB CU YD) 720.8	
1 Calculated on the basis of 2 Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9 3 In the entire batch as mixed 4 In that portion of the concrete containing aggregate smaller than the 1-1/2-in. sieve * For "other cement," pozzolan, second size of fine aggregate, as may be required.			
REMARKS: Condition of mix, workability, plasticity, bleeding, etc.			

CRD FORM NO 553  
REV MAR 1972

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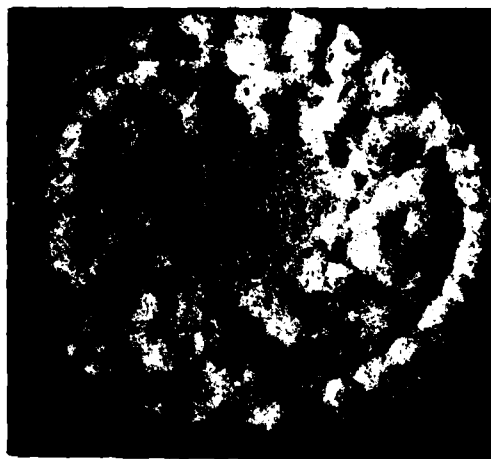
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PROJECT NAME		SYMBOL SERIAL NO	DATE						
CONCRETE REQUIRED FOR		MIXTURE NO <b>F-7</b>							
MATERIALS									
PORTLAND CEMENT, SS-C-192, TYPE <b>I</b> ADDITIONS: BRAND AND MILL <b>Marquette</b>		POZZOLON OR OTHER CEMENT TYPE <b>None</b> SOURCE							
		AIR-ENT ADMIXTURE TYPE <b>None</b> AMOUNT <sup>1</sup>							
FINE AGGREGATE		COARSE AGGREGATE							
TYPE <b>Limestone</b>  SOURCE		TYPE <b>Limestone</b> size <b>3/4 in.</b>  SOURCE							
MATERIALS	SAMPLE SERIAL NO	SIZE RANGE	COARSE AGGR. (%)						
PORTLAND CEMENT									
Steel Fibers	Hooked (50/0.50)								
FINE AGGREGATE	CL-2 MS-1(2)	No. 4 - 200							
COARSE AGGREGATE (A)	CL-2 G-1(3)	No. 4 - 3/4 in.							
COARSE AGGREGATE (B)									
COARSE AGGREGATE (C)									
COARSE AGGREGATE (D)									
MIXTURE DATA		SPECIMEN DATA							
MATERIALS	MIX. BY WEIGHT	S S D WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)	CYLINDERS			BEAMS		
				SIZE	NO	AGE	PSI	SIZE	NO
PORTLAND CEMENT	1.00	657	3.341						
Steel Fiber	0.14	95	0.199						
FINE AGGREGATE	2.26	1484	8.808						
COARSE AGGREGATE (A)	2.32	1522	8.969						
COARSE AGGREGATE (B)									
COARSE AGGREGATE (C)									
COARSE AGGREGATE (D)									
WATER	0.54	355	5.683						
AIR									
TOTAL		4113	27.000						
W C (WT)	0.54		S A % VOLUME	49					
SLUMP (IN)	1.75		THEO UNIT WT (LB CU FT)						
BLEEDING (%)			ACTUAL UNIT WT (LB CU FT)	152.3					
AIR CONTENT (%)	2.3		THEO CEMENT FACT (LB CU YD)						
AIR CONTENT (%)			ACTUAL CEMENT FACT (LB CU YD)	657					
<sup>1</sup> Calculated on the basis of <sup>2</sup> Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9. <sup>3</sup> In the entire batch as mixed. <sup>4</sup> In that portion of the concrete containing aggregate smaller than the 1-1/2-in. sieve. <sup>5</sup> For "other cement," pozzolan, second size of fine aggregate, as may be required.									
REMARKS: Condition of mix, workability, plasticity, bleeding, etc.									



APPENDIX B  
TYPICAL SURFACE CONDITIONS OF SPECIMENS  
AFTER 72 HOURS OF TESTING



a.  $W/C = 0.72$



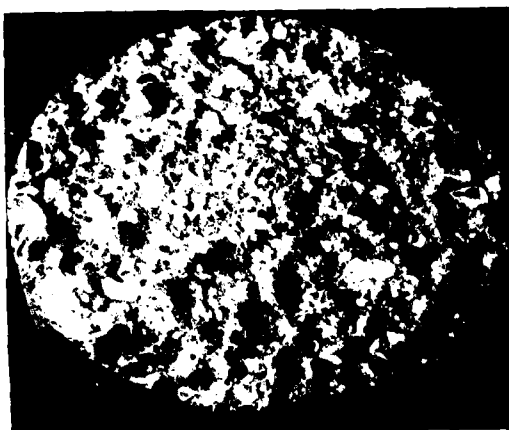
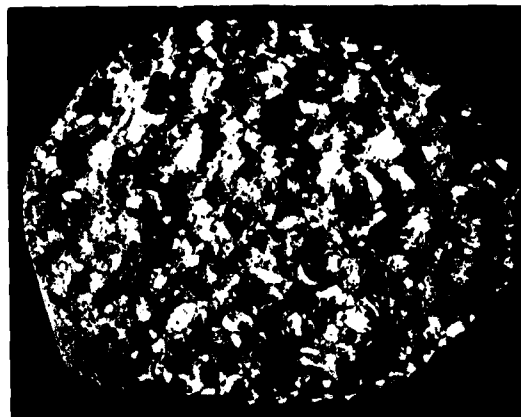
b.  $W/C = 0.54$



c.  $W/C = 0.40$

Figure B1. Conventional concrete, limestone

a.  $W/C = 0.72$



b.  $W/C = 0.54$

c.  $W/C = 0.40$

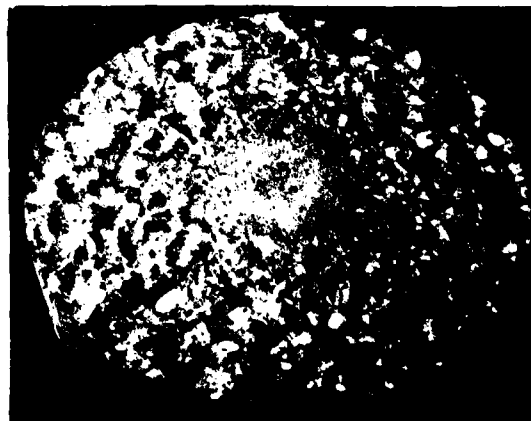
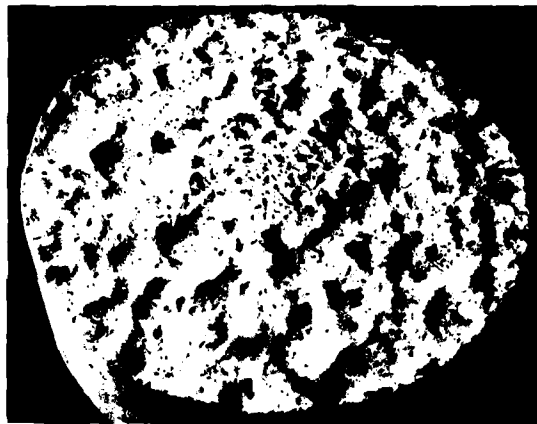


Figure B2. Conventional concrete, chert

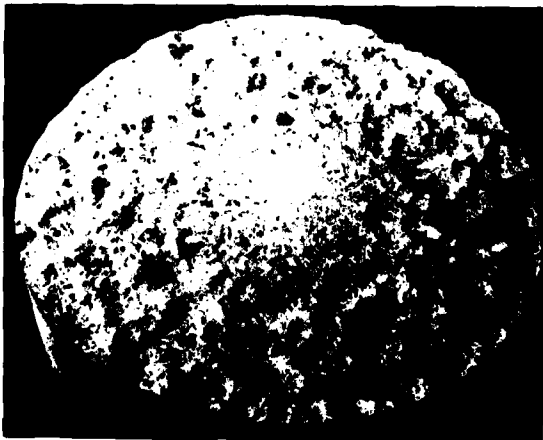
B3



a.  $W/C = 0.72$



b.  $W/C = 0.54$



c.  $W/C = 0.40$

Figure B3. Conventional concrete, trap rock

a.  $W/C = 0.72$



b.  $W/C = 0.54$



c.  $W/C = 0.40$



Figure B4. Conventional concrete, quartzite

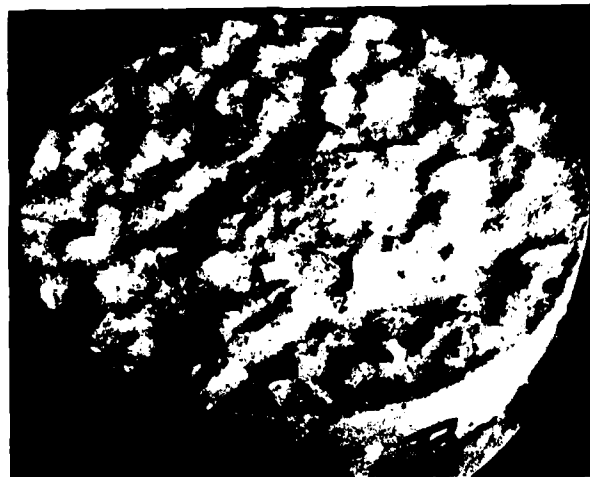


a. Granite

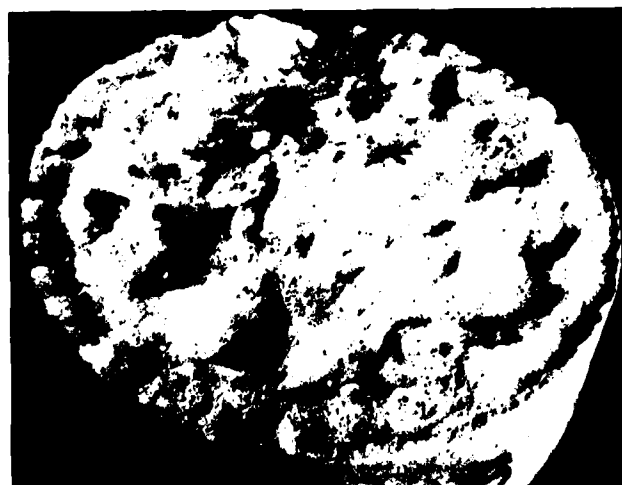


b. Slag

Figure B5. Conventional concrete,  
W/C = 0.50



a. Granite

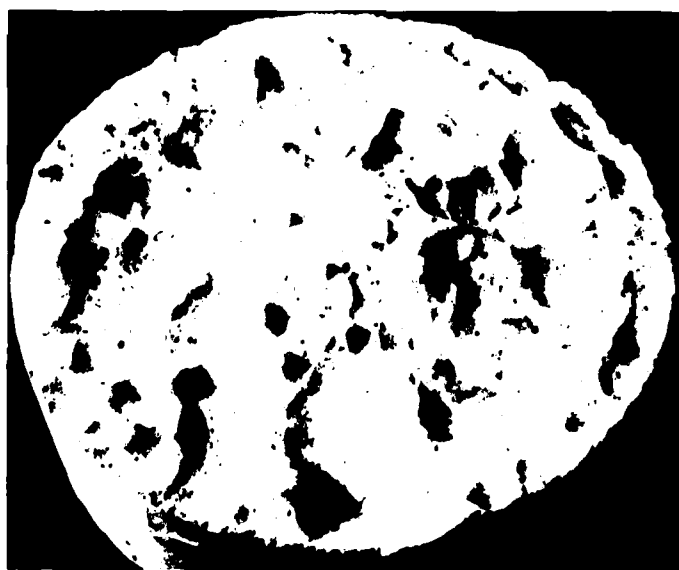


b. Slag

Figure B6. Conventional concrete,  
 $w/c \approx 0.55$



a. Vacuum treated

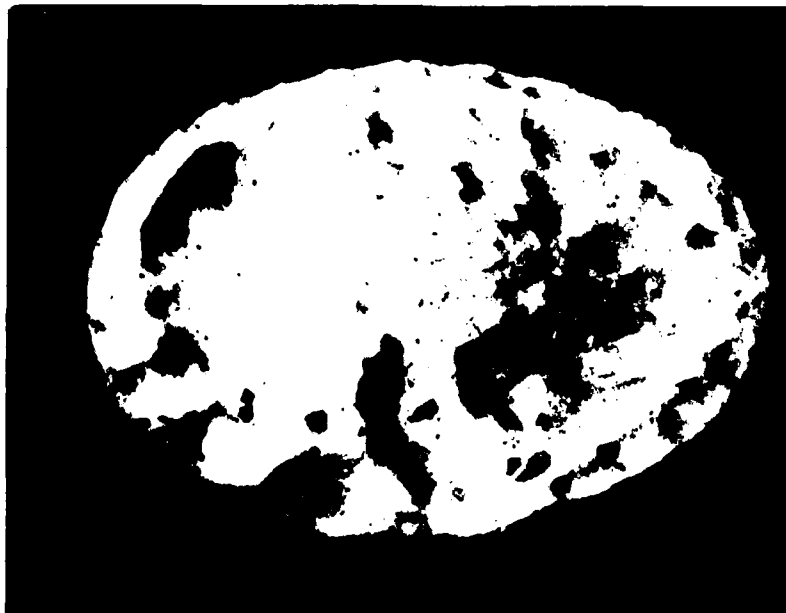


b. Control (no vacuum treatment)

Figure B7. Conventional concrete,  
limestone, W/C = 0.72

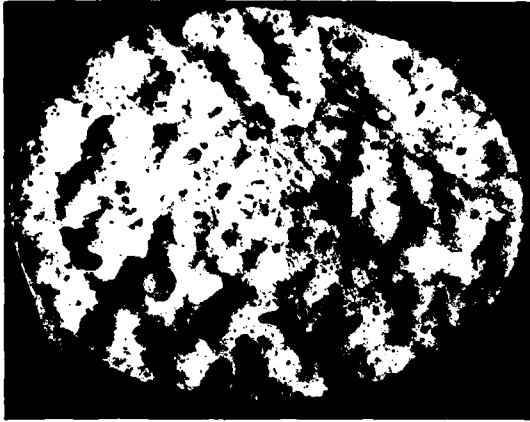


a. Vacuum treated

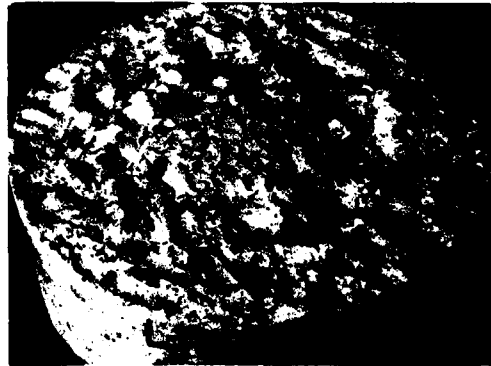


b. Control (no vacuum treatment)

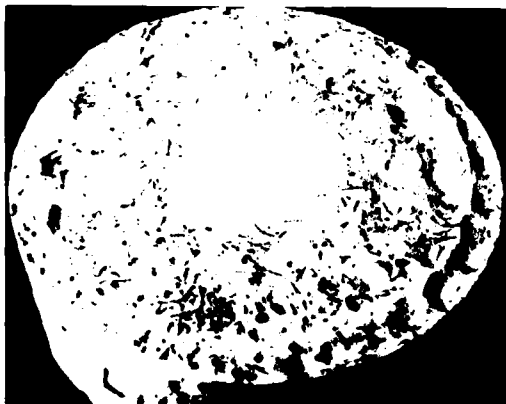
Figure B8. Conventional concrete,  
limestone, W/C = 0.54



a. Conventional concrete



b. Fiber-reinforced concrete



c. Polymer-impregnated fiber-reinforced concrete

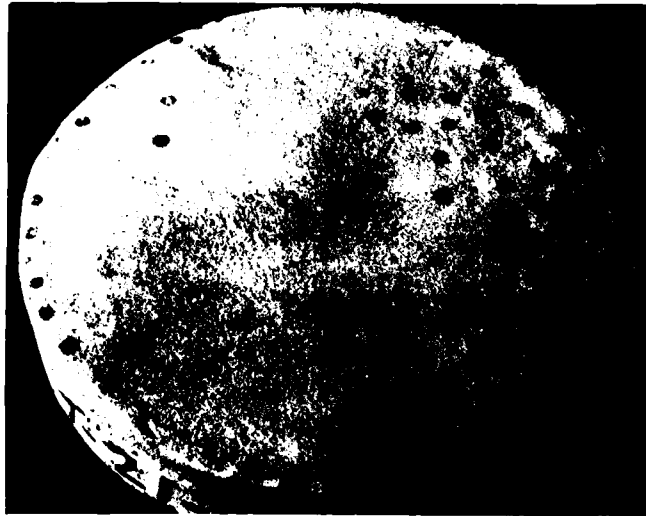
Figure B9. Siliceous gravel concretes,  $W/C = 0.43$



a. GS-300/GS-600



Figure B10. Polyurethane coatings



a. Low modulus



b. High modulus

Figure B11. Epoxy resin mortar coatings



Figure B12. Acrylic mortar coating

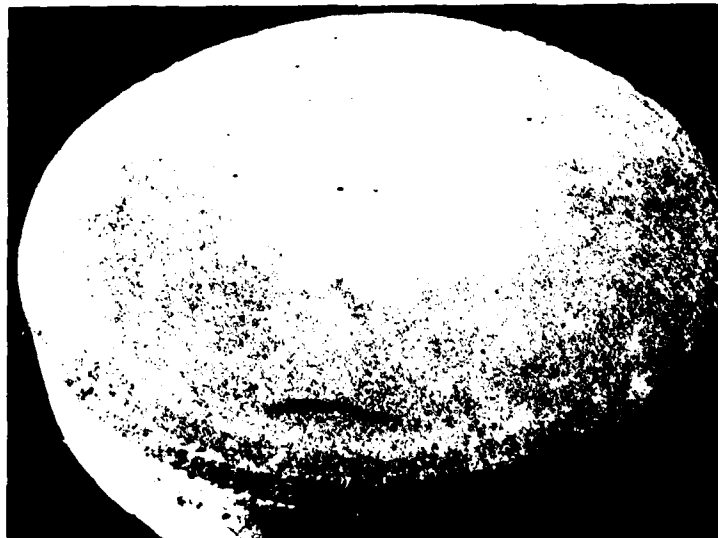


Figure B13. Furan resin coating

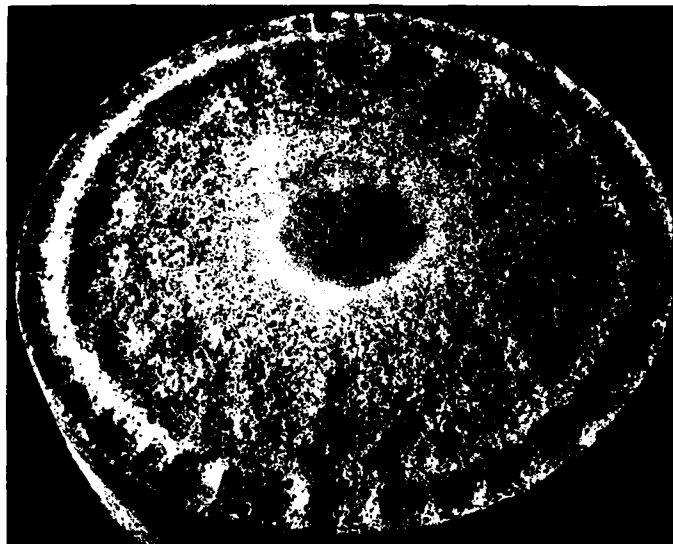


Figure B14. Iron aggregate topping

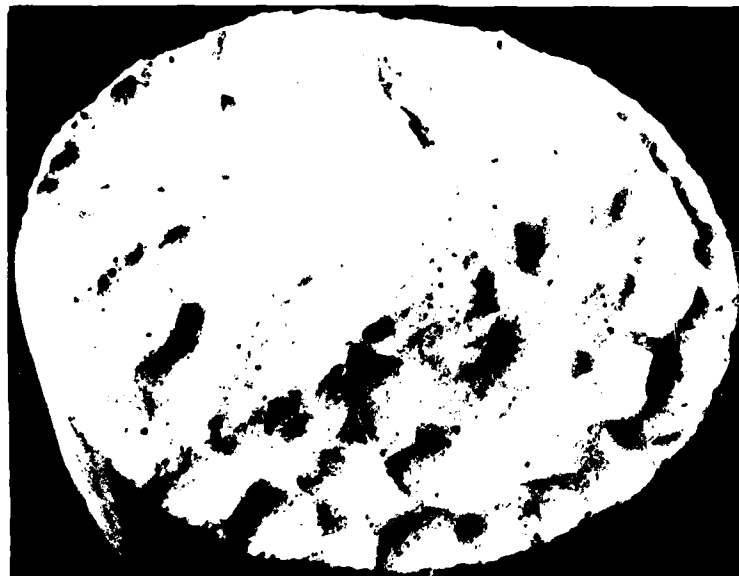
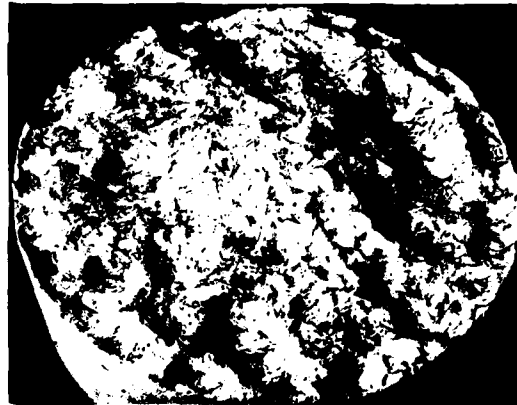
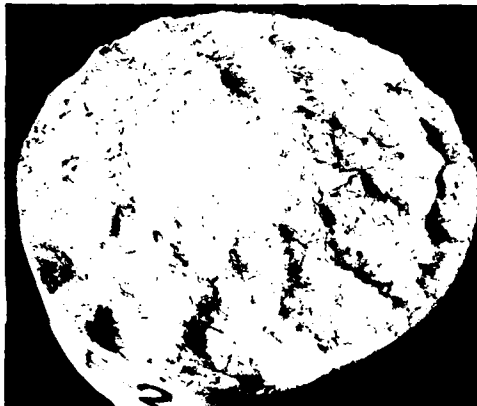


Figure B15. Conventional concrete with 25 percent fly ash replacement (limestone, W/C = 0.54)

a.  $W/C = 0.72$



b.  $W/C = 0.54$



c.  $W/C = 0.40$

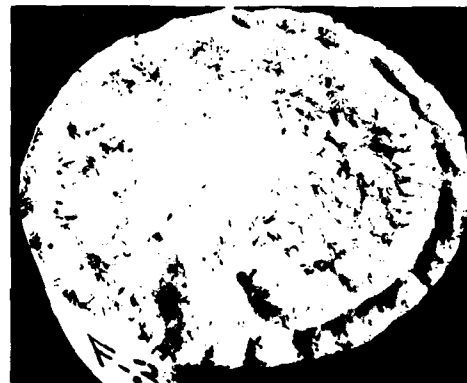
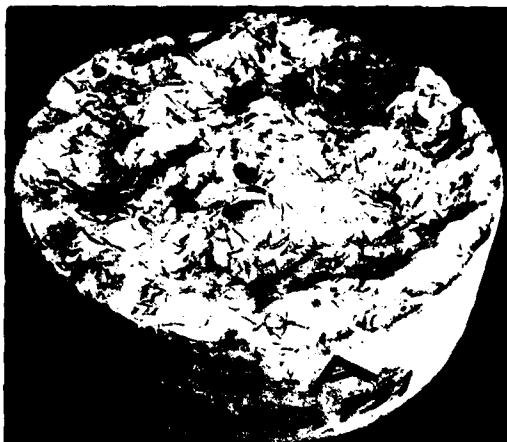
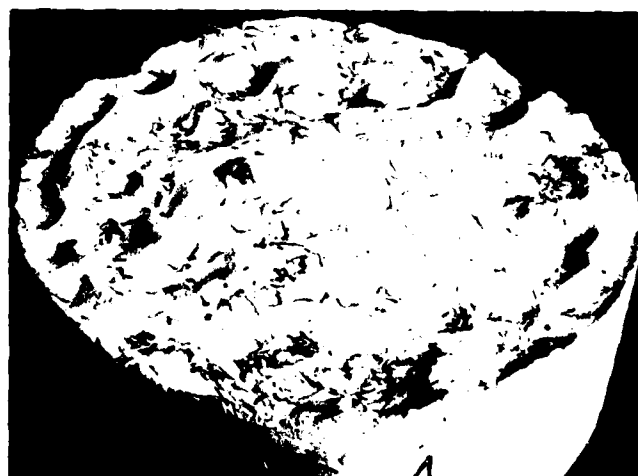


Figure B16. Fiber-reinforced concrete, 0.5-in. straight fiber



a.  $W/C = 0.72$



b.  $W/C = 0.54$

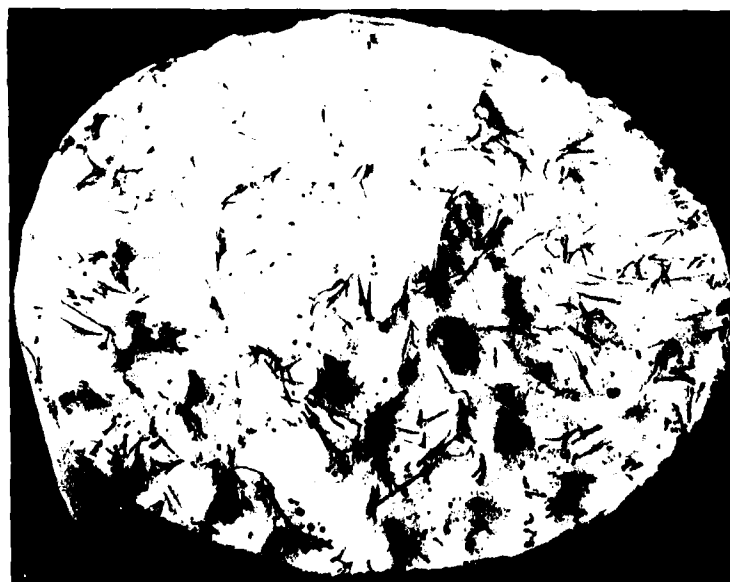


c.  $W/C = 0.40$

Figure B17. Fiber-reinforced concrete, 1.0-in. straight fiber



a. 50-mm hooked fiber



b. 30-mm hooked fiber

Figure B18. Fiber-reinforced concrete,  $W/C = 0.54$ , hooked fibers

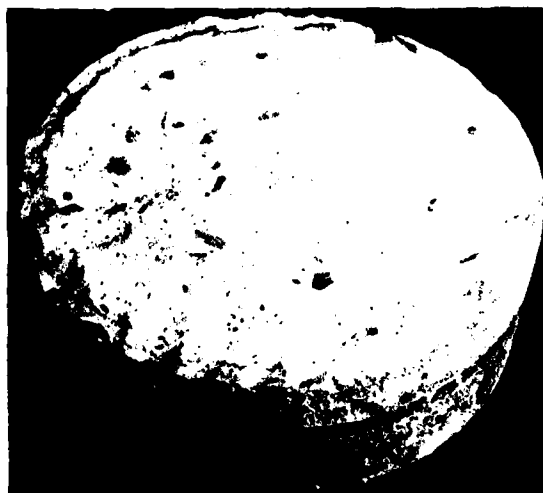


Figure B19. Polymer-impregnated concrete

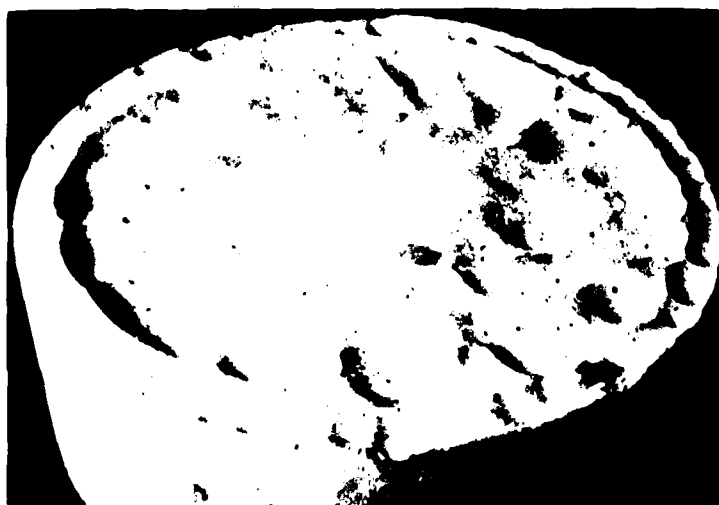
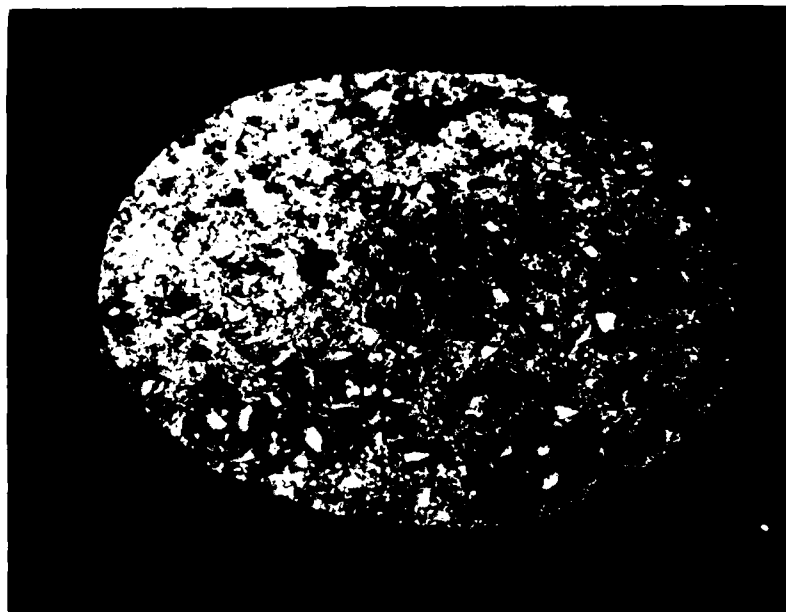
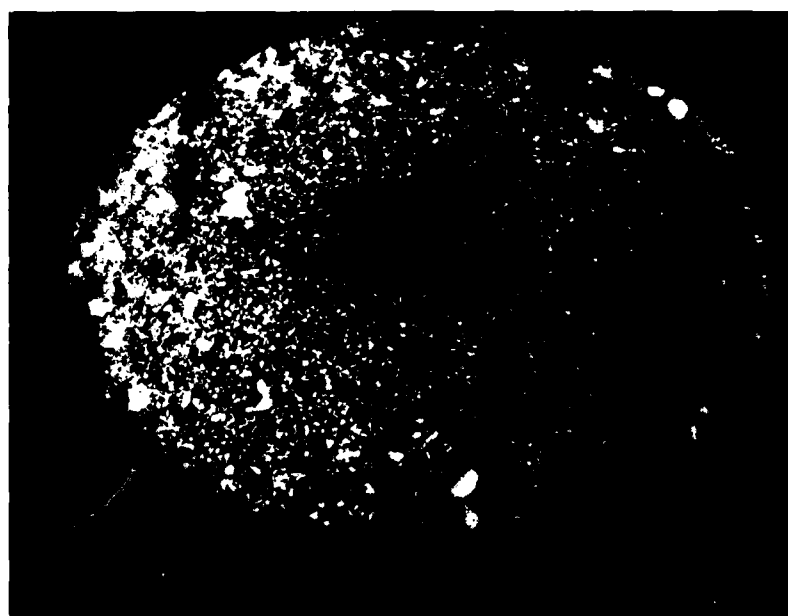


Figure B20. Polymer portland cement concrete



a. MMA



b. Vinyl ester

Figure B21. Polymer concretes

APPENDIX C  
PROPOSED TEST METHOD FOR ABRASION-EROSION  
RESISTANCE OF CONCRETE  
(UNDERWATER METHOD)

PROPOSED  
TEST METHOD FOR ABRASION-EROSION  
RESISTANCE OF CONCRETE  
(UNDERWATER METHOD)  
CRD C -80

1. Scope

1.1 This method covers a procedure for determining the relative resistance of concrete surfaces to abrasion-erosion under water. This procedure simulates the abrasive action of waterborne particles (silt, sand, gravel, and other solids). This method is not intended to provide a quantitative measurement of the length of service that may be expected from a specific concrete.

Note: Other test methods for abrasion of concrete, all of which test in air, are

- (a) CRD C 52 Rotating-Cutter method
- (b) CRD C 58 Sand-blast method (ASTM C 418)
- (c) CRD C 60 Rotating disk, Dressing wheel, and Ball-bearing methods for slabs (ASTM C 779)

2. Applicable Documents

2.1 CRD C 117 Test Method for Resistance to Abrasion of Small Size Coarse Aggregates by Use of the Los Angeles Machine (ASTM C 131).

2.2 CRD C 145 Test Method for Resistance to Abrasion of Large-Size Coarse Aggregate by Use of the Los Angeles Machine (ASTM C 535).

3. Significance and Use

3.1 This test method is intended to simulate qualitatively the behavior of swirling water containing suspended and transported solid objects that produce abrasion of substrates to produce pot holes and related effects. The significance and use of the method is to provide a relative evaluation of the resistance of surfaces of concrete to such action. The results are expected to be useful in selection of materials, mixtures, and construction practices for use where such action is to be expected.

4. Apparatus

4.1 Rotating Device - A drill press or similar device with a chuck capable of holding and rotating the agitation paddle (see para 4.3) at a speed of 1200 rpm shall be used.

4.2 Steel Container - A steel pipe, approximately 12 in. (304.8 mm) inside diameter by 18 in. (457.2 mm) high, fitted with a watertight steel base shall be used. The details of a typical steel container being used for abrasion tests are shown in Figure 1.

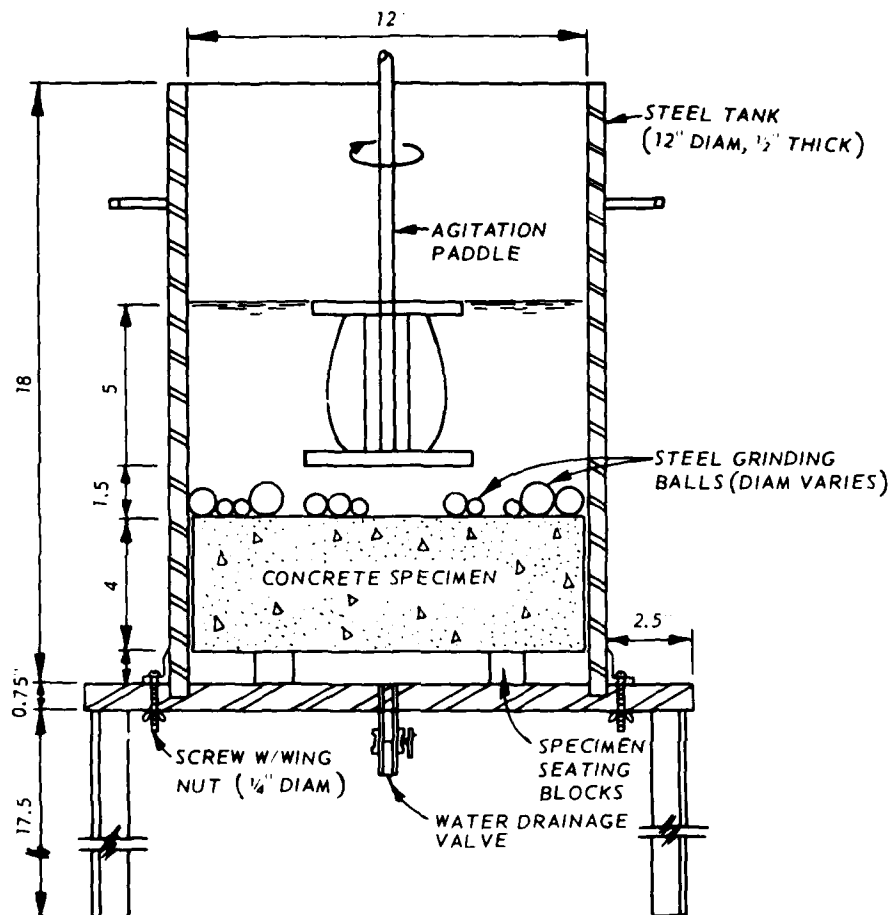


Figure 1. Test Apparatus (U. S. customary units)

4.3 Agitation Paddle - An agitation paddle similar to that shown in Figure 2 shall be used.

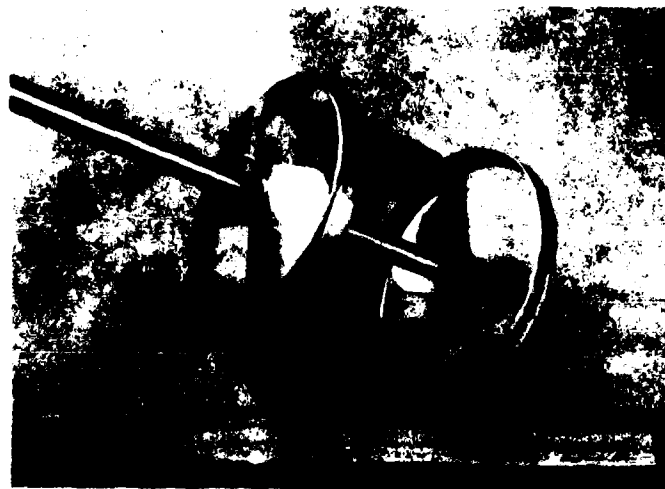


Figure 2. Agitation Paddle

Note: A suitable paddle is Model PS-21 manufactured by the Jiffy Mixer Company, Inc., 17981 Sky Park Circle, Suite G, Irvine, California 92714.

4.4 Abrasive Charges - Seventy steel grinding balls as specified in Table 1 shall be used.

Table 1  
ABRASIVE CHARGES

No. of Steel Grinding Balls	Diameter in. (mm)
10	1.00 $\pm$ 0.05 (25.4 $\pm$ 0.1)
35	0.75 $\pm$ 0.05 (19.1 $\pm$ 0.1)
25	0.52 $\pm$ 0.05 (12.7 $\pm$ 0.1)

4.5 Scales - A platform scale having a capacity of 50 lb (22.68 kg) or more and sensitive to 0.05 lb (0.02 kg) or less shall be used.

#### 5. Specimens

5.1 The test specimens shall be cylindrical in shape, approximately 11-3/4 in. (298.5 mm) in diameter and 4 in. (101.6 mm) high, and may be

either molded from concrete or cored from hardened concrete. They shall be soaked in water for a minimum of 48 hr prior to testing.

## 6. Test Procedures

6.1 Surface dry the specimen, determine and record mass to the nearest 0.01 lb (5.0 g).

6.2 Place specimen in the steel container with the surface to be tested facing up.

6.3 Position the specimen so that its surface is normal to the drill shaft and the center of the specimen coincides with the drill shaft.

6.4 The agitation paddle shall be mounted in the drill press. The bottom of the agitation paddle shall be approximately 1-1/2 in. (38.1 mm) above the surface of the specimen.

6.5 Place the abrasive charges on the surface of the specimen and add water to approximately 6-1/2 in. (165.1 mm) above the surface of the specimen.

6.6 Set the drill press at 1200 rpm and start the machine. A test period of 24 hr generally produces significant abrasion in most concrete surfaces, but it is recommended to extend the period to 72 hr, if simulation of more severe abrasion is desired. Additional testing time may be required for special concrete that is highly resistant to abrasion. Weigh the specimen per paragraph 6.7 at 12-hr intervals to obtain a time versus abrasion loss curve.

6.7 The specimen shall be removed from the container every 12 hr and at the end of the test period. Flush off the abraded material, surface dry, weigh, and record to the nearest 0.01 lb (5.0 g).

## 7. Calculations

7.1 The abrasion loss is calculated by the following equation

$$L = \frac{M_i - M_f}{M_i} \times 100$$

where

$L$  = abrasion-erosion loss, percent by mass

$M_i$  = mass of the surface-dry specimen before test

$M_f$  = mass of the surface-dry specimen after test

8. Report

The report shall include the following:

8.1 Plot the time versus abrasion loss of at least three test specimens and determine the average line.

8.2 Record the mixture proportions (including cement content and water-cement ratio), types and grading of fine and coarse aggregates, Los Angeles abrasion test results (CRD C 117 and C 145), type and extent of troweling, curing details, age of concrete when tested, specimen dimensions, and other information necessary to describe the features of the concrete and the surface tested.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Liu, Tony C

Maintenance and preservation of concrete structures; Report 3: Abrasion-erosion resistance of concrete / by Tony C. Liu. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.

59, [36] p., [17] leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; C-78-4, Report 3)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under CWI Work Unit 31553.

References: p. 59.

1. Abrasion tests. 2. Aggregates. 3. Concrete erosion. 4. Concrete structures. 5. Concrete tests. 6. Concretes. 7. Erosion resistance (Concrete). 8. Fiber reinforced concrete. 9. Laboratory tests. 10. Polymer concrete. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; C-78-4, Report 3.

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